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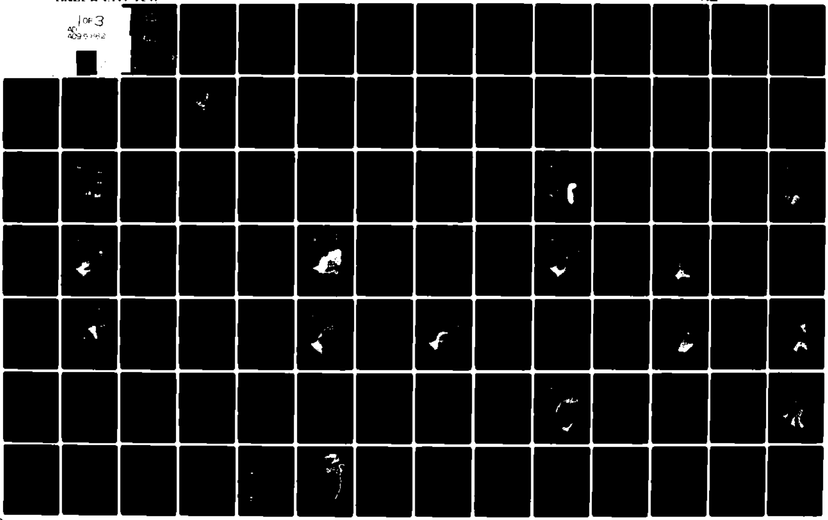

Coastal Ecosystems Management Inc.

Contract No. DACW63-72-C-0142

Energy Man

Final Report

ENVIRONMENTAL ASSESSMENT OF THE TRINITY RIVER DISCHARGE ON PRODUCTIVITY IN TRINITY BAY

Prepared for

Fort Worth District, U.S. Corps of Engineers

A Systems Approach for All Coastal Environmental Problems

AD A095862

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The major objective of this report is to investigate environmental questions before additional steps can be taken to implement the completion of the Trinity River canalization project. Major consideration is given to: 1) the possible effect that the waters of the Trinity River drainage might have upon the overall biological productivity of its estuary and the greater Galveston Bay system; 2) how much runoff water from the basin must be guaranteed to the Galveston Bay system in order to provide optimum conditions for a smoothly running ecosystem; 3) the possible effect of reduced runoff and subsequently reduced sediment load in maintaining the

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20. various habitats and ecological niches in Trinity Bay. Recommendations of the report were: 1) to maintain a vigil against the increase of phosphate in Trinity Bay to guard against inhibition of plant production; 2) to insure that a sufficient river discharge is maintained so that a salinity gradient will exist from river mouth to bay mouth; 3) to permit at least 1,300,000 acre feet of water to be discharged into Trinity Bay to flush the bay twice a year; 4) to establish a minimum one-year environmental monitoring program to acquire the necessary data for continued management of the river discharge needed to maintain productivity in Trinity Bay; 5) to evaluate all hurricane protection levee systems and tidal exchange structures surrounding the Galveston Bay area before any proposed alterations of the Trinity River flow are made; 6) to survey all county and municipal waste disposal criteria to determine whether there is a need for a stricter pollution code or stricter enforcement of the present code.

A

ENVIRONMENTAL ASSESSMENT OF THE TRINITY RIVER DISCHARGE ON PRODUCTIVITY IN TRINITY BAY

FINAL REPORT

Prepared for

FORT WORTH DISTRICT, U.S. CORPS OF ENGINEERS

Contract No. DACW63-72-C-0142

Prepared by

COASTAL ECOSYSTEMS MANAGEMENT, INC.

Robert H. Parker, Dehn E. Solomon, and
Gerald D. Smith

Coastal Ecosystems Management, Inc.
3600 Hulen Street
Fort Worth, Texas 76107

15 September 1972

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15 September 1972

Colonel F. H. Henk
District Engineer
Fort Worth District
U.S. Army Corps of Engineers
P.O. Box 17300
Fort Worth, Texas 76102

Attention: Trinity River Section

Dear Colonel Henk:

Transmitted herewith is the final report of Phase I and Phase II of Contract DACW 63-72-C-0142, entitled "Environmental Study of the Trinity River Basin." The major emphasis of this work concerned the study of future controls needed on the Trinity River Basin to maintain normal productivity levels in Trinity Bay.

Phase I of this contract summarized the literature pertinent to the contract and resulted in the additional bibliography given separately. Phase II included a short field study to complement and add to the existing literature, and a final correlation of the literature and our own field data.

This report summarizes what was a short term study. We feel much additional investigation is necessary. This report is preliminary and does not necessarily constitute the final project concept to be adopted and approved by the U.S. Army Corps of Engineers.

Very truly yours,

COASTAL ECOSYSTEMS MANAGEMENT, INC.

Robert H. Parker

Robert H. Parker
President

RHP:el
Enclosure

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We wish to thank the following people for supplying information and able assistance: Mr. John Montgomery and Mr. Robert Eastwood, U.S. Geological Survey, U.S. Department of Interior, Austin, Texas; and Mrs. Dee Crawford, Environmental Protection Agency, Dallas, Texas.

INTRODUCTION

Several important environmental questions must be answered before additional steps can be taken to implement the completion of the Trinity River canalization project. Major consideration must be given to: 1) what is the possible effect that the waters of the Trinity River drainage might have upon the overall biological productivity of its estuary and the greater Galveston Bay system into which the Trinity estuary empties; 2) how much runoff water from the basin must be guaranteed to the Galveston Bay system in order to provide optimum conditions for a smoothly operating ecosystem; 3) what possible effect would reduced runoff and subsequently reduced suspended sediment load have in maintaining the various habitats and ecological niches in Trinity Bay. In order to obtain preliminary answers to these questions, Coastal Ecosystems Management, Inc. carried out an *in depth* survey of previously published information on the Trinity River-Galveston Bay system and then proceeded to collect its own environmental data, in the Trinity estuary region, relating to those ecological variables for which little or no published information was available.

Overall biological productivity in a river-fed bay-type estuary is governed by a large number of environmental factors; the discharge and local runoff of the river being two of the more important ones. Many of the water quality parameters of the bay estuary are directly correlated with river discharge and runoff. Trinity Bay, of the Galveston Bay complex, is a river-fed bay-type estuary, thus the biological productivity in that bay could certainly be greatly influenced by variations in discharge of the Trinity River. The major objective of this report is to define those factors primarily responsible for the maintenance of biological productivity in Trinity Bay and to relate those factors to the varying discharge volumes of the Trinity River. This report summarizes the published and unpublished literature on biological productivity and its environmental controls in this bay. In addition, our own short-term field studies are discussed in order to define the present levels of productivity and to obtain information on environmental variables not previously measured.

In recent years, as greater importance has been attributed to estuaries as nursery grounds for America's commercial fisheries, more and more concern has been expressed concerning the degradation of our estuaries (Fruh, Armstrong, and Copeland, 1972; Copeland, Odum, and Cooper, 1972; Parker, and Blanton, 1970; Diener, 1964; Reid, 1956). One of the primary areas of concern has been the minimum amount of fresh water needed to maintain a normal salinity gradient in an estuary. A salinity gradient ranging from salt water to fresh water is a characteristic of all estuaries and its maintenance is necessary because many animal species need different salinities for optimum growth during their various life stages. Maintenance of the salinity gradient is largely a function of fresh water inflow to the estuary. However, the minimum and optimum amounts of fresh water necessary for a smoothly operating ecosystem are not yet firmly established and are subject to considerable controversy.

Trinity Bay (Fig. 1) is located approximately 60 miles east of Houston, Texas, in the wet, subhumid climatic zone (Parker, 1960). Trinity

Bay is part of the Galveston Bay complex and is the arm that extends to the northeast of that complex. The bay is approximately 14.8 miles long and 10 miles wide, with a surface area of approximately 128 square miles. It has a mean depth of eight feet and a volume calculated at 2.85×10^{10} ft^3 (Lankford, Clark, Warme, and Rehkemper, 1969). These authors also calculated the area of adjacent marshes to be 7.07 square miles, plus river delta marshes of 26.66 square miles in area.

The bay is surrounded by a modern delta system of the Trinity River to the northeast, most of the northwest and southeast sides are Pleistocene fluvial-deltaic systems, a modern marsh system occurs northeast of Smith Point, and the higher land northeast of Smith Point is a Pleistocene barrier-strandplain system (Fisher, McGowen, Brown, and Groat, 1972). It is interesting to note that these same authors list six different forms of the modern marsh system; *i.e.*, 1) closed brackish, 2) salt water, 3) fresh to brackish, 4) coastal lakes, 5) fresh water, and 6) swamp.

Lankford, *et al.* (1969) list seven categories of surface sediments in the bay; *i.e.*, 1) marsh, 2) deltaic, 3) shoreline, 4) shell reefs, 5) inlet deposits, 6) bay bottom, and 7) artificial. Lankford, *et al.* (1969) consider the bay bottom (clayey sand and clayey silt) as the dominant sediment of the bay area.

Many investigators have sampled this bay and a great many studies have resulted from their efforts. Some of the more important investigations were carried out by Stevens (1962); Gloyna, and Malina (1964); U.S. Department of Interior, Geological Survey-Water Resources Division (1964, 1965; Trent, Pullen, Mock, and Moore (1967); Culpepper, Blanton, and Parker (1969); Pullen, and Trent (1969); Baldauf, von Conner, Holcombe,

Fig. 1. Location of Trinity Bay and its relationship to the Texas coast.

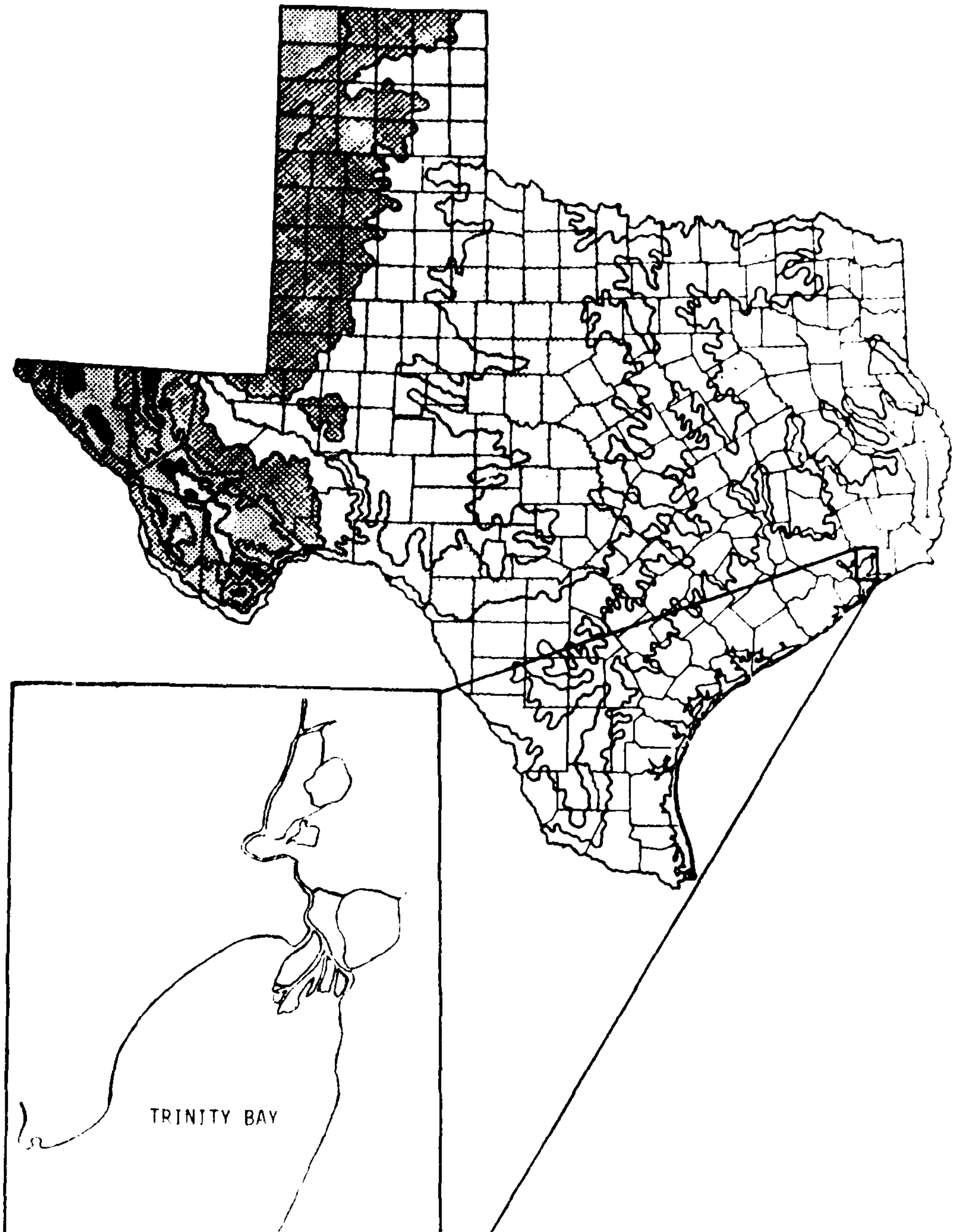

TRINITY BAY

Fig. 2. Sources of station data--other than C.E.M.'s.

LEGEND

1 Baldauf, von Conner, Holcombe, and Truesdale (1970)

2 Gloyna and Malina (1964), Bureau of Commercial Fisheries

3 Copeland and Fruh (1970)

4 Huston (1971)-- Tracor, Galveston Bay Stations

5 Pullen and Trent (1969)

6 Stevens (1962)

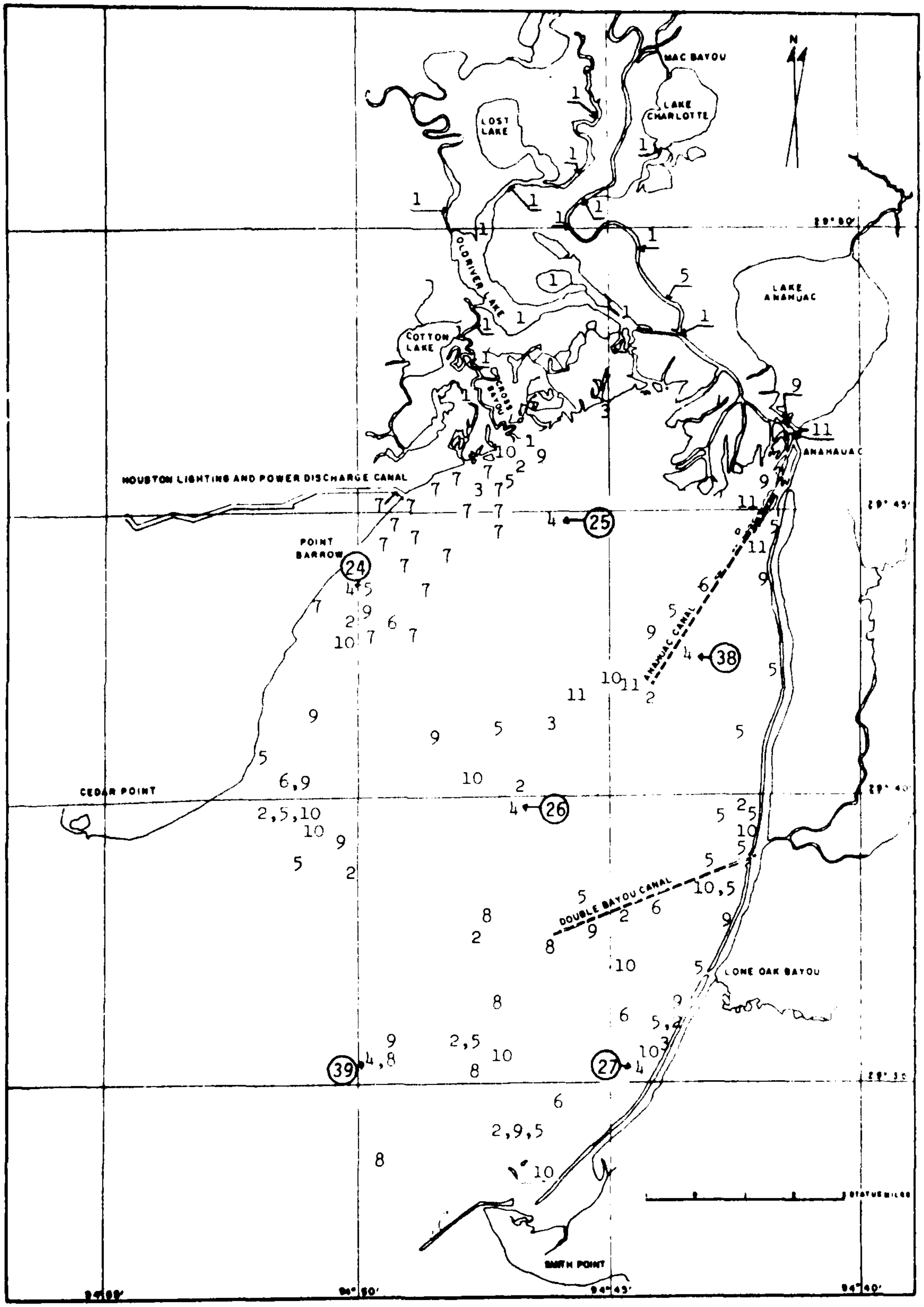
7 Strawn (1972)

8 Gloyna and Malina (1964), Texas Department of Health, 1963

9 Gloyna and Malina (1964), Texas Department of Health, 1958

10 Trent, Pullen, Mock, and Moore (1967)

11 U.S. Geological Survey (1962-1965)


MAC BAYOU
LAKE CHARLOTTE
LOST LAKE
N
OLD RIVER LAKE
LAKE ANAHUAC
COTTON LAKE
CROSS BAYOU
ANAHUAC
HOUSTON LIGHTING AND POWER DISCHARGE CANAL
POINT BARROW
ANAHUAC CANAL
CEDAR POINT
DOUBLE BAYOU CANAL
LONE OAK BAYOU
SMITH POINT
STATUTE MILES

and Truesdale (1970); Copeland, and Fruh (1970); Huston (1971); Strawn (1972). The stations occupied by these various authors are shown on Figure 2. Inspection of that figure shows that parts of Trinity Bay have been very well sampled, while large areas of the bay have never been sampled at all. None of the investigations cited approached any sort of complete canvassing of the bay. Data obtained during many of these sampling programs cannot be correlated with collections of data from other programs because different parameters were measured or different methods were used in each of the sampling programs. While there is a vast body of knowledge of the common environmental parameters, such as temperature and salinity, there remain large areas of the bay from which data on less frequently measured variables are needed in order to define the baseline conditions of this estuary.

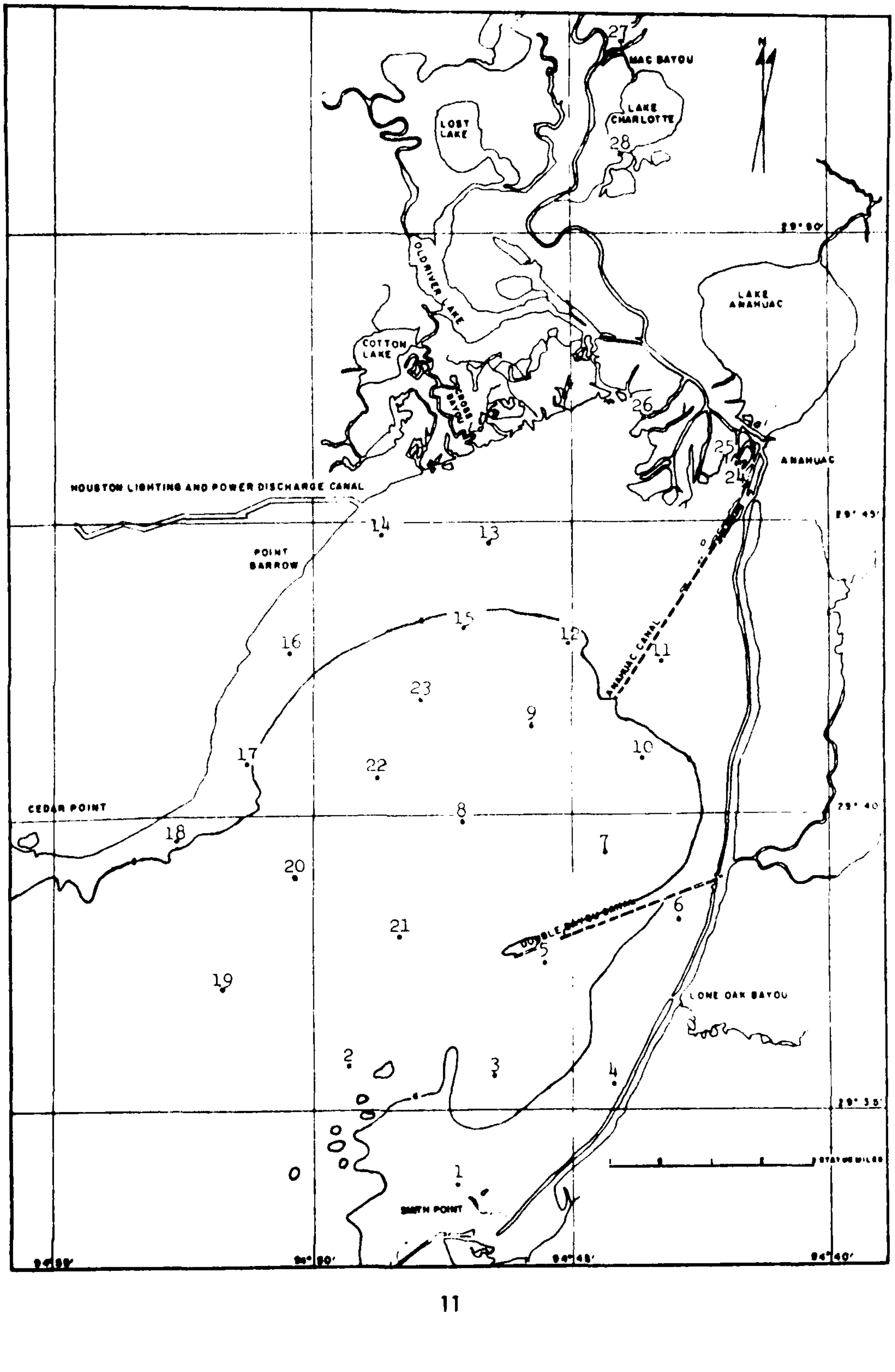
METHODS

All field measurements, except temperatures, were determined from bottom water samples collected with a loosely stoppered, weighted bottle, lowered to the bottom, then filled. Field data were taken August 1-4, 1972, from the brackish to freshwater marshes adjacent to the lower Trinity River, from the Trinity Bay proper, and from a true salt marsh on the shores of East Bay, in order to obtain data representative of all the present conditions on the estuary (Fig. 3). The field trip data will be compared with historical data in order to present a more complete picture of the environmental "health" of this estuary.

Chemical-Physical Parameters

Temperatures of both air and surface water were measured with an armored hand thermometer calibrated in 1.0° C. units. Dissolved oxygen (DO) in ppm was measured with a Hach Chemical Company, direct reading, portable engineer's laboratory (DR-EL) with conductivity meter. The sodium azide modification of the Winkler titration method is used with this portable laboratory. Salinity as conductivity was determined with the conductivity probe of the Hach portable laboratory. The conductivity meter is designed for fresh water so that those water samples taken from the bay required from one to several times dilution in order to be measured within the range of the meter. The reading from the meter was the multiplied by the dilution factor. Water samples were rechecked for salinities through a full range conductivity meter in the laboratory.

Fig. 3. C.E.M. station locations within Trinity Bay region.


MAC BAYOU
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OLD RIVER LAKE
COTTON LAKE
LAKE ANAHUAC
ANAHUAC
HOUSTON LIGHTING AND POWER DISCHARGE CANAL
POINT BARROW
ANAHUAC CANAL
CEDAR POINT
LONE OAK BAYOU
SMITH POINT
29°45'
29°40'
94°45'
94°40'

A Beckman Model G pH meter was used initially to determine pH and Eh (reduction-oxidation potential) until moisture and shock of the boat travel rendered it inoperable. Remaining pH determinations were made with the Hach portable laboratory using colorimetric methods. The Hach portable laboratory also was used to measure hydrogen sulfide (H_2S) in bottom water samples, although no values greater than 0.1 ppm were recorded. Turbidity in Jackson Turbidity Units was determined colorimetrically with the Hach portable laboratory.

Values given in this report for nitrogen concentrations represent the sum of nitrate and nitrite nitrogen. The values were obtained with the Hach portable laboratory, which uses the modified diazotization (1-Naphthylamine-Sulfanilic Acid) method, a form of the cadmium reduction method. Phosphate values also were obtained with the Hach portable laboratory, and the values given are for orthophosphate only. The water was analyzed by the addition of ammonium molybdate and acid to the sample, followed by a stannous reducing agent. Total organic carbon values were determined on a Beckman 44 total organic carbon analyzer, using 200 microliter size samples for greatest accuracy. All metal ion determinations were done on a Perkin-Elmer atomic absorption spectrophotometer.

Biological and Sediment Parameters

Bacterial counts were made from samples taken from the top centimeter layer of the sediment cores and from the centimeter of water lying immediately above the sediment-water interface. Bacterial counts were made by both direct count and luminescence biometer. Since the luminescence biometer has the greater precision, and the counts by the two methods were generally within the same order of magnitude, only the more objective luminescence biometer counts are used in this report.

Total plankton samples were obtained by using a plankton net with an eight-inch wide mouth and No. 24 mesh, which was towed at three knots for three minutes. All samples contained ctenophores (small jellyfish) which clogged the meshes so that it was impossible to quantify the samples. Zooplankton was very abundant, thus the plankton samples have been analyzed on general terms only.

Quantitative samples of benthic organisms were obtained with a 1/25 m^2 Van Veen grab sampler. The mud samples were washed through a 250 micron mesh screen in the field and fixed with 10 percent Formalin. In the laboratory the preserved samples were washed through a series of U.S. Standard screens with mesh openings of 4.0 mm, 2.0 mm, 1.0 mm, 0.5 mm, and 0.25 mm. The organisms in each of the fractions were mechanically picked by hand, identified, and counted under dissecting microscopes.

Cores of the bottom sediments, for both bacterial studies and sediment size analysis, were obtained by hand by plunging lengths of cellulose butyrate core liner filled with water into the sediments, stoppering the liner, and slowly removing the core barrel from the bottom. Gravity on the water column holds the core in the tube. On the deck, the length of core liner containing the core was cut off eight inches above the sediment surface, and the core was frozen, while still in the field, with dry ice.

Sediment analyses included sieving of the coarse fraction (greater than 62 microns) and pipette analyses of settling velocities for the fine fraction (less than 62 microns). The methods used are those of Shepard (1954) and they basically define the sediments as percentages of sand, silt, and clay.

RESULTS OF C.E.M.'s FIELD AND LABORATORY ANALYSES

It is scientifically "very risky" to draw too many conclusions from a single field trip. Environmental conditions in an estuary are continually changing, so that in order to obtain truly meaningful data it is necessary to monitor the environment over at least one annual cycle.

Water Quality Factors

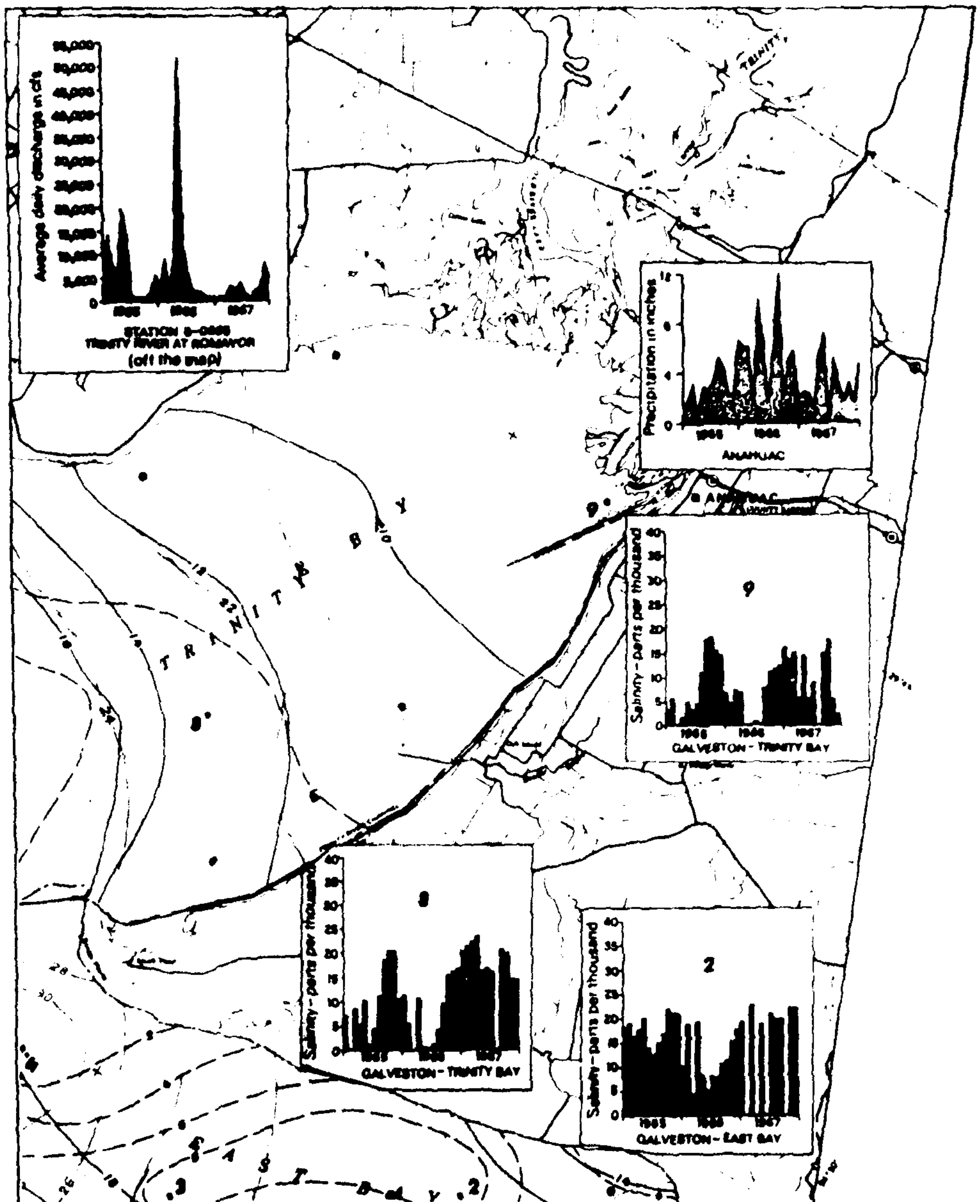
Temperature

Although a single set of water temperatures are not very meaningful, values obtained in August, 1972, are given to show that normal midsummer conditions were extant. Knowledge of water temperatures is needed to interpret oxygen values. Surface water temperatures ranged from 25.8° to 29.0° C. which can be considered normal for August (Table I). Summer temperatures in Trinity Bay may range as high as 35° C. and as low as 2° C. in winter (Parker, 1960). Shidler (1961) states the hydrographic climate (a plot of salinity *vs* temperature) of Trinity Bay is the freshest and has the widest temperature range of the whole Galveston Bay complex. An example of salinity patterns, rainfall, and river discharge for a three year period, as given by Fisher, *et al.* (1972), is depicted on Figure 4.

Dissolved Oxygen

Dissolved oxygen values for bottom water ranged from 3.10 ppm to 13.90 ppm (Fig. 5). *Questions should arise as to the accuracy of determinations* whenever dissolved oxygen values over 9 ppm are observed; since the saturation point of oxygen in water ranges from 7.63 ppm at 30° C. up

Fig. 4. Rainfall, river discharge, and surface salinity patterns (Fisher, *et al.* (1972).



RAINFALL, STREAM DISCHARGE, AND SURFACE SALINITY

- Calculated average surface salinity 1965-1967 contour values in parts per thousand
- Extreme low surface salinity (periods of relatively high rainfall and runoff) May 1966 contour values in parts per thousand
- Extreme high surface salinity (periods of relatively low rainfall and runoff) 1965-1967 contour values in parts per thousand
- Salinity measurement station supplying monthly data for graph
- Salinity measurement station supplying additional data for contouring
- Rainfall recording station supplying monthly data for graph
- Discharge measurement station supplying monthly data for graph

TABLE I

STATION DATA FROM TRINITY BAY, TEXAS

AUGUST 1-4, 1972

Station	Wind Direction	Wind Speed mph	Temperature ° C.	Salinity $^{0}/oo$	Turbidity JTU
TB 1	SW	5	25.8	15.6	--
TB 2	SW	4.5	27.2	17.0	--
TB 3	SW	6.5	27.4	16.9	--
TB 4	S	8-10	27.5	15.9	--
TB 5	S	6.5	27.0	16.3	23
TB 6	S	6	27.8	15.6	19
TB 7	S	10-12	28.0	15.7	13
TB 8	S	14-16	--	14.9	21
TB 9	S	16	28.0	13.3	30
TB 10	S	16-17	29.0	14.4	28
TB 11	S	16-18	28.5	12.6	30
TB 12	S	14-15	28.0	11.8	29
TB 13	S	6	28.0	14.0	36
TB 14	S	7	28.4	17.0	8
TB 15	S	7	27.8	15.7	38
TB 16	SW	7-8	27.0	17.0	62
TB 17	S	30	27.0	17.5	53
TB 18	S	7	27.0	17.0	67
TB 19	S	7-9	28.0	17.5	28
TB 20	S	8	28.0	18.3	34
TB 21	S	12	27.0	18.3	14
TB 22	S	10-12	27.5	17.9	32
TB 23	S	12-13	27.0	16.2	30
TB 24	S	6-8	28.0	11.8	19
TB 25	SE	8-10	27.0	--	35
TB 26	SE	12	27.0	--	25
TB 27	SE	10-12	30.0	--	37
TB 28	SE	6-10	--	--	28

TABLE I (continued)

Station	Eh* mv	H_2S ppm	Mg ppm	Ca ppm	Mg/Ca	Mercury ppb	Arsenic ppm
TB 1	--	0.1	22.0	48	.46	10	<.02
TB 2	--	0.1	20.5	25	.82	2	<.02
TB 3	229	0.1	20.5	39	.52	2	<.02
TB 4	209	0.1	20.5	20	1.02	1	<.02
TB 5	229	0.1	13.0	32	.41	1	<.02
TB 6	259	0.1	19.0	68	.28	2	<.02
TB 7		0.1	19.0	68	.28	1	<.02
TB 8	249	0.1	14.5	65	.22	1	<.02
TB 9	249	0.1	12.0	75	.16	1	<.02
TB 10	249	0.1	14.5	68	.21	1	<.02
TB 11	209	0.1	13.0	65	.20	2	<.02
TB 12	249	0.1	13.0	68	.19	4	<.02
TB 13	179	<0.1	58.0	140	.41	8	<.02
TB 14	129	<0.1	58.0	126	.46	4	<.02
TB 15	139	<0.1	58.0	100	.58	64	<.02
TB 16	129	<0.1	58.0	140	.41	16	<.02
TB 17		<0.1	35.0	100	.35	16	<.02
TB 18		<0.1	58.0	100	.58	32	<.02
TB 19		<0.1	58.0	140	.41	24	<.02
TB 20		<0.1	58.0	168	.34	8	<.02
TB 21		<0.1	58.0	86	.67	20	<.02
TB 22		<0.1	58.0	86	.67	4	<.02
TB 23		<0.1	52.0	140	.37	24	<.02
TB 24		0.1	52.0	114	.46	8	<.02
TB 25			14.5	68	.21	4	<.02
TB 26			19.0	65	.29	4	<.02
TB 27			3.8	28	.14	5	<.02
TB 28			4.2	32	.13	4	<.02

*corrected values by adding +249 mv

TABLE I (continued)

Station	pH units	Dissolved Oxygen ppm	Nitrites Nitrates mg/l	Phosphates mg/l	Total Carbon ppm	Organic Carbon ppm
TB 1	8.30	5.43	.04	--	27.5	1.5
TB 2	8.10	5.81	.05	1.00	25.5	0.5
TB 3	8.05	6.59	.06	.30	27.0	2.0
TB 4	8.00	6.98	.06	.80	28.0	2.0
TB 5	8.30	11.63	.05	.89	25.0	1.0
TB 6	7.90	3.10	.06	.88	30.0	6.0
TB 7	7.80	13.90	.06	.91	27.0	2.0
TB 8	7.50	5.43	.06	.92	24.5	1.5
TB 9	7.90	7.36	.12	.80	24.5	0.5
TB 10	7.90	5.43	.08	.68	30.0	4.0
TB 11	7.80	7.17	.06	.78	26.5	0.5
TB 12	8.00	6.98	--	.86	27.5	1.5
TB 13	7.00	4.65	.14	1.60	57.0	5.0
TB 14	7.50	4.65	.29	1.95	44.0	3.0
TB 15	8.20	5.04	.09	1.12	130.0	88.0
TB 16	7.40	4.65	.06	1.00	108.0	68.0
TB 17	8.42	5.04	.10	.99	88.0	28.0
TB 18	8.40	5.04	.01	1.10	140.0	137.0
TB 19	8.41	4.26	.06	1.00	84.0	40.0
TB 20	8.35	5.04	.04	.95	84.0	12.0
TB 21	8.47	5.04	.06	.95	94.0	6.0
TB 22	8.50	5.04	.05	.96	88.0	12.0
TB 23	8.40	--	.08	.98	102.0	19.0
TB 24	8.10	3.49	.06	.68	84.0	4.0
TB 25	8.50	--	.06	.56	30.0	3.0
TB 26	8.40	11.00	.05	.59	33.0	7.0
TB 27	7.70	8.00	.07	.20	34.0	7.0
TB 28	7.70	9.00	.08	.25	37.0	10.0

TABLE I (continued)

Station	Bacterial Count cells/ml		Bottom Animals		Benthic
	Sediment	Water	1/25 m^2	1 m^2	Diversity*
TB 1	1.96×10^7	6.40×10^4	6,346	158,650	0.18
TB 2	9.98×10^9	2.38×10^6	113	2,825	3.53
TB 3	1.27×10^5	9.35×10^5	17	425	11.76
TB 4	7.54×10^9	--	1,077	26,925	1.02
TB 5	6.64×10^9	1.09×10^6	58	1,450	1.72
TB 6	2.57×10^9	9.37×10^5	537	13,425	1.30
TB 7	1.54×10^9	7.34×10^5	488	12,200	1.02
TB 8	1.21×10^9	1.27×10^6	63	1,575	3.17
TB 9	1.26×10^9	1.31×10^5	55	1,375	5.45
TB 10	1.73×10^9	3.30×10^5	215	5,375	0.93
TB 11	2.70×10^9	1.66×10^5	389	9,725	1.79
TB 12	1.03×10^{10}	2.86×10^6	390	9,750	1.02
TB 13	7.04×10^9	8.37×10^5	1,222	30,550	0.57
TB 14	3.30×10^9	7.98×10^5	68	1,700	10.30
TB 15	3.04×10^9	3.09×10^5	626	15,650	0.79
TB 16	3.34×10^9	6.99×10^5	1,390	34,750	0.43
TB 17	3.52×10^9	3.67×10^5	2,079	51,975	0.33
TB 18	1.28×10^9	3.22×10^5	194	4,850	4.63
TB 19	3.20×10^8	8.40×10^4	177	4,425	1.69
TB 20	5.60×10^7	1.62×10^5	251	24,950	1.99
TB 21	--	--	5,044	126,100	0.28
TB 22	1.60×10^8	2.03×10^5	380	9,500	1.05
TB 23	2.50×10^8	2.98×10^5	272	6,800	1.10
TB 24	--	--	1,804	45,100	0.55

TABLE I (continued)

Station	Bacterial Count cells/ml		Bottom Animals		Benthic Diversity*
	Sediment	Water	1/25 m^2	1 m^2	
TB 25	5.00×10^7	2.04×10^5			
TB 26	2.21×10^9	5.05×10^5			
TB 27	7.50×10^8	1.71×10^5			
TB 28	1.77×10^8	6.87×10^4			
TB 29	1.37×10^8	--			

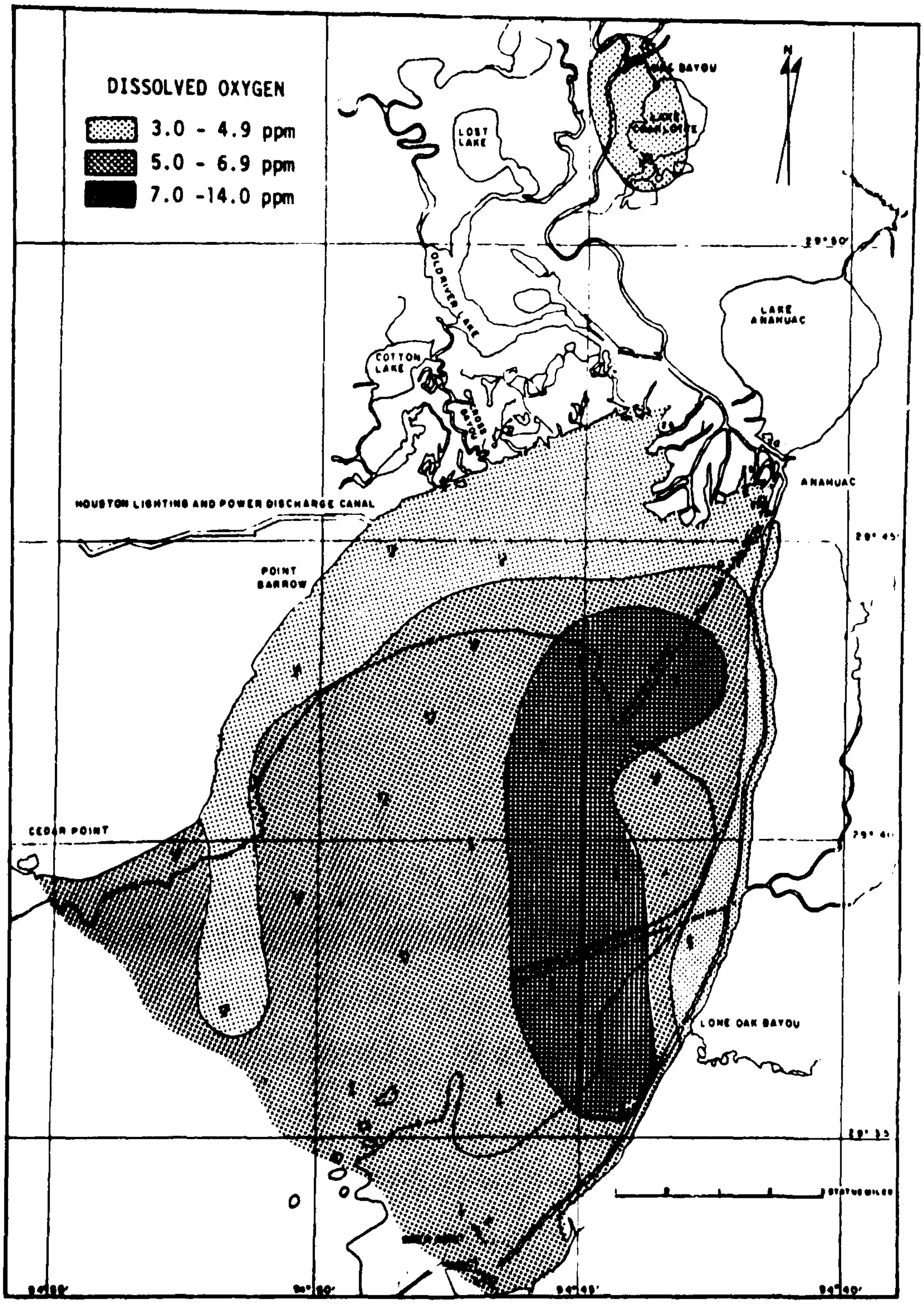
$$* \ DI = \frac{\text{Number of species} \times 100}{\text{Number of individuals}}$$

to 12.80 ppm at 5° C. (Bernard Johnson Engineers, 1971). At the temperatures observed by the C.E.M. field crew, the dissolved oxygen values at complete saturation should have ranged only from 7.8 ppm to 8.8 ppm. Other investigators routinely found the dissolved oxygen values in Trinity Bay to be above saturation at high summer temperatures (Gloyna, and Malina, 1964; Parker, Blanton, Slowey, and Baker, 1969; Dupuy, Manigold, and Schulze, 1970; Espey, Hays, Bergman, Buckner, Huston, and Ward, 1971; Travis, 1972; Williams, 1972). The important fact revealed in the literature and in our own studies of dissolved oxygen levels is that all values are above 4 ppm, the minimum considered as necessary to sustain warm water biota (Environmental Protection Agency, 1971). A possible explanation of these high O_2^+ values can be offered. Apparently, the metabolism of an estuary revolves around the balance struck between producers (plants) and consumers (animals) in the water. If producers (creating a surplus of oxygen) predominate, it is possible to have supersaturation of oxygen.

Dissolved oxygen values below 4 ppm were observed at four stations. Two of these stations were in areas with the freshest water, Mac Bayou in Liberty County and Lake Charlotte, both several miles up the Trinity River. The third station was in the Trinity River channel at Anahuac, and the fourth station was in the bay, 1/4 mile off the mouth of Double Bayou.

It is somewhat difficult to explain the lower oxygen values in the fresh water, as it is well known that fresh water holds more oxygen than salt water. Relatively high total organic carbon (TOC) values were found at these stations, which would suggest high biological oxygen demand (BOD), thus oxygen may be depleted in these areas. A general pattern of dissolved

Fig. 5. Distribution of dissolved oxygen values as parts per million (ppm), Trinity Bay region, Texas.


DISSOLVED OXYGEN
3.0 - 4.9 ppm
5.0 - 6.9 ppm
7.0 -14.0 ppm
N
LOST LAKE
OLD RIVER LAKE
COTTON LAKE
LAKE ANAHUAC
ANAHUAC
HOUSTON LIGHTING AND POWER DISCHARGE CANAL
POINT BARROW
CEDAR POINT
LONE OAK BAYOU

oxygen values can be hypothesized (Fig. 5) which shows low values on the west side, normal values throughout most of the bay, and highest values just offshore of the eastern shore. There does not appear to be any of the other "mapped" variables which show a similar pattern, other than bottom topography.

Salinity

The observed salinities (Fig. 6) in the bay and marshes ranged from 0.14 $^{o}/oo$ in Mac Bayou to 18.30 $^{o}/oo$ in the middle of Trinity Bay. The salinities of the bay stations were much higher than those considered normal for August. Renfro (1960) cites August salinities from 4 to 10 $^{o}/oo$ and Parker (1960) summarizes salinity data for the bay and gives a range of 1 to 10 $^{o}/oo$. Conversations with local inhabitants of the area confirmed that the bay was saltier than it had been in many summers. A normal estuarine gradient, with salinities decreasing upstream in the estuary, can be observed on Figure 6. Note that a tongue of fresh water extends outward from the river into the bay, while another tongue of salt water extends inward from the bay mouth. A more conservative pattern of salinity distribution, from Fisher, *et al.* (1972), is shown on Figure 4 which illustrates mean, greatest maximum, and greatest minimum isotherms. These isotherms, however, are based on relatively few data points and they merely show a gradient from high at the mouth of the bay to low near the river.

Hydrogen Ion Concentration (pH)

Surface water pH data were taken at all stations shown on Figure 7. The range of these values is from 7.0 to 8.5, a normal range for estuarine waters. Much wider ranges of pH have been recorded in the literature, *i.e.*, a range of 6.6 to 9.1 (Blakey, and Kunze, 1971) and a range of 6.2 to 9.4 (Travis, 1972). The C.E.M. pH values differed only 1 pH unit throughout the bay. It should be pointed out that a variation of 1 pH unit can be found in an open estuary depending upon the time of day at which samples were taken. There is normally a large diurnal pH fluctuation associated with biological oxidation and respiration (Espey, *et al.*, 1971). Again, a pattern of values appears which dissects the bay longitudinally. Lowest pH values were observed in the river and in the eddy or quiet northwest portion of the bay. The pH is primarily controlled by photosynthetic activity through regulating $CO_2\uparrow$ content and, in part, by acids, acid generating salts, phosphates, and borates (Blakey, and Kunze, 1971). Thus, runoff from the adjacent land could contain some of the above mentioned substances derived from the periphery of the bay. The water mass, in the northwestern portion of the bay, with the lowest pH's of 7.0 to 7.7 is more typical of river estuarine acidity. On the other hand, pH values in Cedar Bayou were unusually low (5.6 to 6.9) in the area from which the Houston Lighting and Power Company (HL&P) canal takes water to Trinity Bay (Culpepper, Blanton, and Parker, 1969); thus the present low values could be derived from Cedar Bayou. The high pH's of 8.4 to 8.5 in the southwestern part of the bay may reflect Houston Ship Channel water. Normal marine estuary pH's of 7.8 to 8.3 occupy the eastern, sheltered side of the bay.

Hydrogen Sulfide Concentration (H_2S)

Surface and bottom water samples were analyzed for hydrogen sulfide (H_2S). This highly toxic gas is given off by anaerobic bacteria in strongly

Fig. 6. Salinity isohalines as parts per thousands ($^{0}/oo$), Trinity Bay region, Texas.

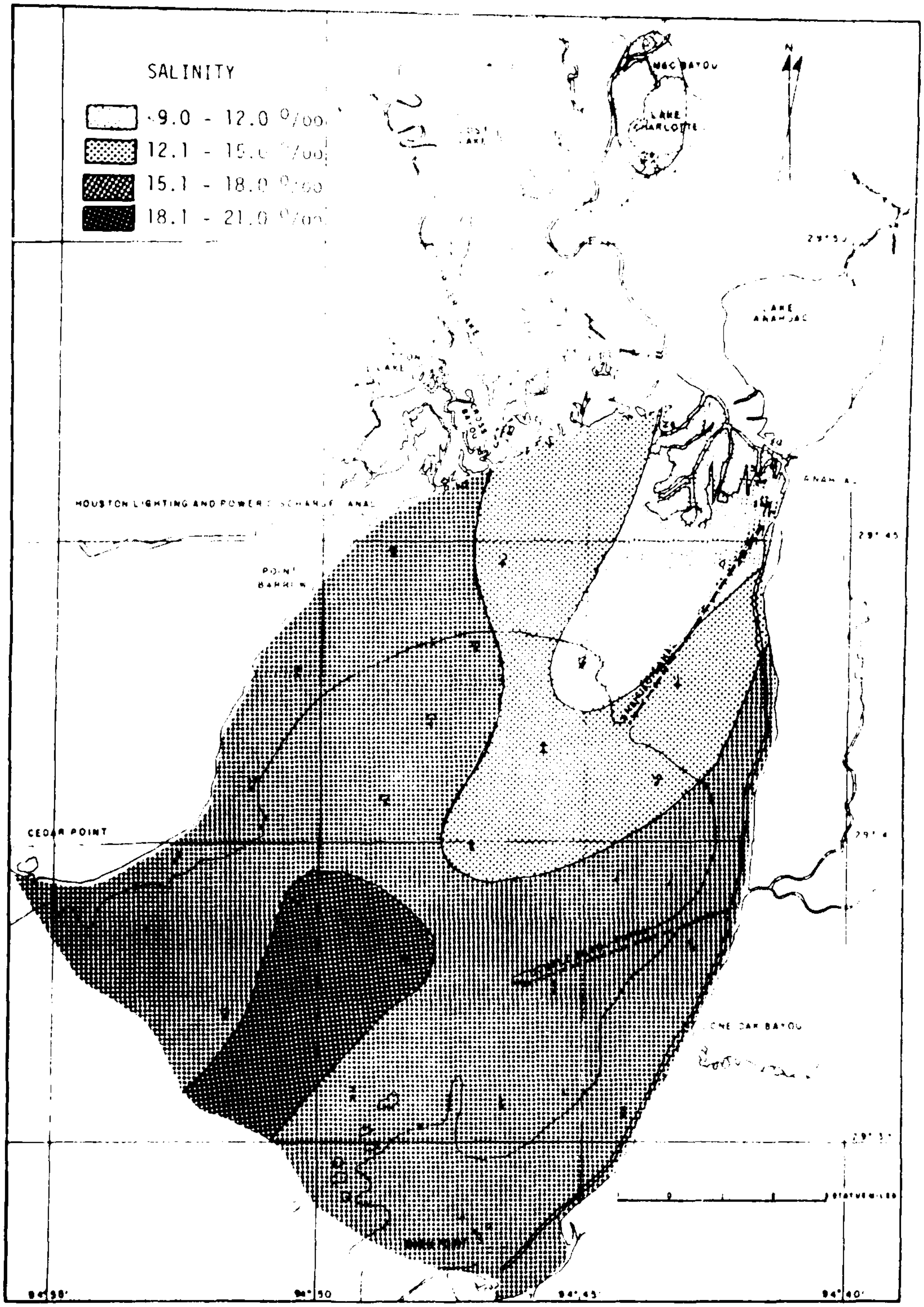
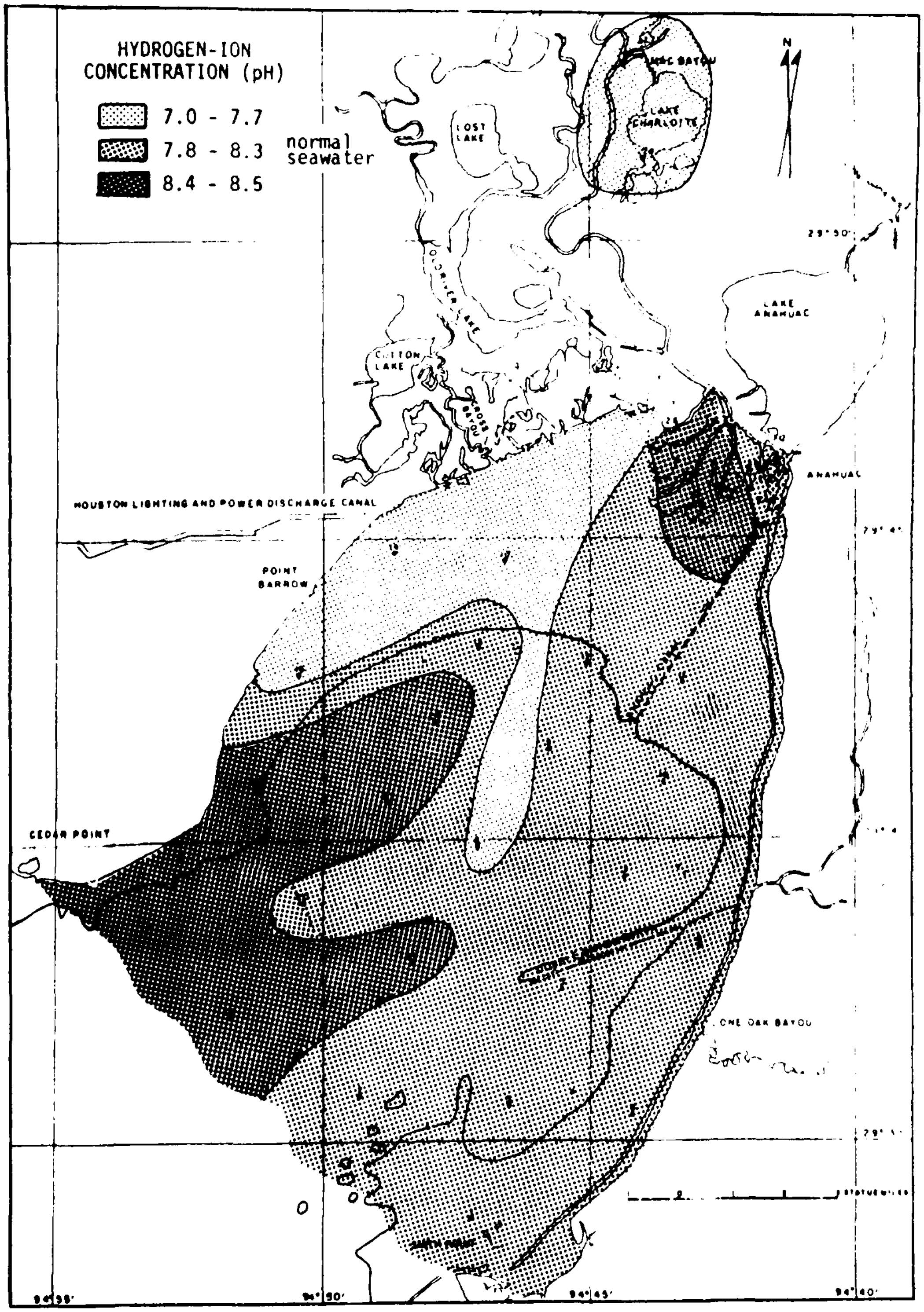

SALINITY
12.1
15.1
18.1 - 21.0
MAC BAYOU
LAKE CHARLOTTE
LAKE ANAHUAC
CEDAR POINT
94°50'
94°45'
94°40'

Fig. 7. Distribution of pH in Trinity Bay region, Texas.


HYDROGEN-ION
CONCENTRATION (pH)
7.0 - 7.7
7.8 - 8.3
normal
seawater
8.4 - 8.5
LOST LAKE
LAKE CHARLOTTE
LAKE ANAHUAC
COTTON LAKE
HOUSTON LIGHTING AND POWER DISCHARGE CANAL
POINT BARROW
ANAHUAC
CEDAR POINT
ONE OAK BAYOU
94°50'
94°45'
94°40'

reducing sediments. The presence of H_2S is an indication of oxygen depletion and reducing chemical conditions; even minute concentrations of the dissolved gas is prohibitive to most benthic invertebrates. Concentrations above 0.1 ppm (the lower limit of detection with the Hach kit) were not observed during this study.

Reduction-Oxidation Potentials (Eh)

In conjunction with pH and H_2S measurements, Eh or redox potentials were determined for bottom water samples (Table I). Reliable Eh information is difficult to obtain as oxidation begins immediately after water samples are brought to the surface. All the Eh measurements taken from our water samples were in the oxidizing range which correlates well with the lack of hydrogen sulfide in the same samples. Negative Eh values along with measurable H_2S would have indicated reducing chemical conditions which for the most part can be limiting to benthic invertebrates. Similar Eh values were found in Cedar Bayou and Trinity Bay (Culpepper, *et al.*, 1969).

Turbidity

Turbidity measured in Jackson Turbidity Units (JTU) was determined for all but four of the stations. Figure 8 is a plot of turbidity values in the bay and shows (as with many other variables) that the bay area can be divided in half longitudinally with less turbid waters in the southeastern half and more turbid waters in the western half. The turbidity pattern can easily be considered a result of the prevailing winds in August, and particularly during our sampling program when winds exceeding 25 mph were experienced (Table 1). The prevailing wind in August is from the southeast which means the entire southeastern side of the bay is more or less protected, or is in a lee situation. At the same time, the northwestern side of the bay feels the full effect of the wind generated waves, thus keeping finer sediments in suspension most of the time.

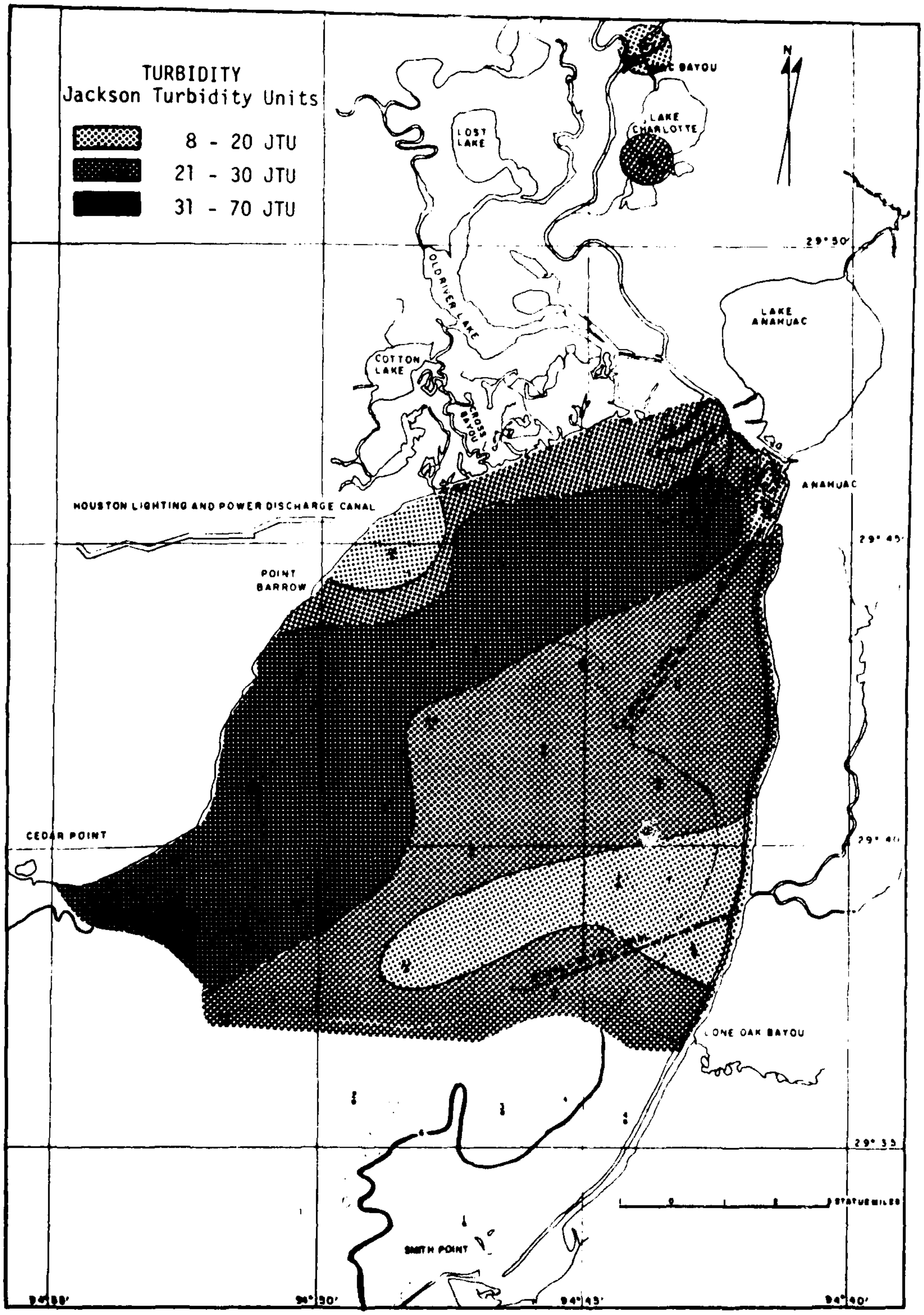
The lower turbidity surrounding the mouth of Double Bayou (Fig. 8) may only indicate that the water from Double Bayou carries less particulate matter than is already in suspension in the bay. The very low value observed at the mouth of the HL&P canal is believed to be a physical interaction of bay water and the discharge water, with some component of the discharge water causing much of the suspended matter to precipitate out.

The very high turbidity measured in Mac Bayou is difficult to explain. There was almost no current that could carry suspended material, and the water appeared relatively clear. However, there is a sulphur processing plant and a petroleum cracking plant further up the bayou which could, through barge traffic and other plant activities, contribute to the higher turbidity of the bayou waters. It is possible that the highest values in the southwest part of the bay may be associated with the Houston Ship Channel.

Metallic ion Concentrations

Concentrations of mercury, arsenic, calcium, and magnesium ions were determined for each bottom water sample. All four ions are of considerable significance in maintaining a smoothly operating ecosystem. The ratio of calcium to magnesium is important to many physiological processes. Both mercury and arsenic are toxic materials, which could be contributed to

Fig. 8. Distribution of turbidity in Trinity Bay region, Texas.


TURBIDITY
Jackson Turbidity Units
8 - 20 JTU
21 - 30 JTU
31 - 70 JTU
N
LOST LAKE
LAKE CHARLOTTE
OLD RIVER LAKE
LAKE ANAHUAC
COTTON LAKE
ANAHUAC
HOUSTON LIGHTING AND POWER DISCHARGE CANAL
POINT BARROW
CEDAR POINT
LONE OAK BAYOU
SMITH POINT
STATUTE MILES
29° 50'
29° 45'
29° 35'
94° 40'

the system by the Houston Ship Channel.

Mercury

Isopleths of the mercury levels for Trinity Bay are displayed on Figure 9, and the exact values are given in Table I. Mercury analyses were included in this study in order to provide us with an indication of human disturbance within the bay. Presence or absence of mercury *per se* has little to do with biological productivity, except that some biological pathways in marine ecosystems can concentrate mercury to dangerous levels in the larger food organisms. Some of the values in the bay were well above the minimum value of 5 ppb established as a dangerous level in human foods (Pure Food and Drug Administration, HEW). The highest value found was 64 ppb, over an order of magnitude higher than the acceptable level. It should be noted that in general, values over 5 ppb emanate from the Trinity River, while excessive values of over 20 ppb appear to be derived from the Houston Ship Channel (Fig. 9). It is conceivable that continued high mercury level inputs from the Ship Channel could result in dangerous food levels for such organisms as blue crabs and oysters.

Arsenic

Arsenic, like mercury, was measured only as a possible indicator of human disturbance within the Trinity Bay estuary. As all values were less than 0.02 ppm (Table I), there was no need to isopleth their distribution throughout the estuary. Carapella (1972) states that the range of values for arsenic in aquatic systems is not well known, but that 0.02 ppm is the highest reported seawater value. Natural levels in diluted or estuarine waters could be even lower. Higher concentrations of arsenic could result from human disturbance. It is apparent from our brief survey that there does not appear to be an industrial source of arsenic in the vicinity of the bay.

Magnesium-Calcium Concentrations (Ratio of Mg/Ca)

Magnesium and calcium are two relatively abundant ions in seawater and their ratio is often used as an indicator of water quality. The normal Mg/Ca ratio for seawater is about 3.12 or 1.27 ppm of magnesium to 0.40 ppm of calcium (Sverdrup, Johnson, and Fleming, 1942). The concentration of calcium increases in freshwater, while magnesium normally decreases upstream of an estuary. The concentration of calcium is important to many multicellular organisms in its involvement with nerve conductance and other ionic control systems. Excess magnesium in seawater can cause severe shock in fish, and too little or too much calcium has a considerable effect upon the physiology of other marine animals and plants (Parker and Blanton, 1970).

The Mg/Ca (ratios) derived from the analyses of the waters in the study area are isoplethed in Figure 10. These isolines show a trend similar to those displayed for salinity (Fig. 6). This is no surprise, as the change in Mg/Ca is a direct function of the salinity gradient and the constancy of composition of seawater. The range of all values for this estuary appears low until one realizes that the mouth of the Trinity River can be considered as at least 10 miles upstream from the source of Gulf water. The ratios of Mg/Ca, 10 miles up the Brazos and Colorado Rivers from their mouths, were 0.5 and 0.7 respectively (Parker, *et al.*, 1969), which compare favorably with those of Trinity Bay, ranging from 0.16 to

Fig. 9. Distribution of mercury as parts per billion (ppb), Trinity Bay region, Texas.

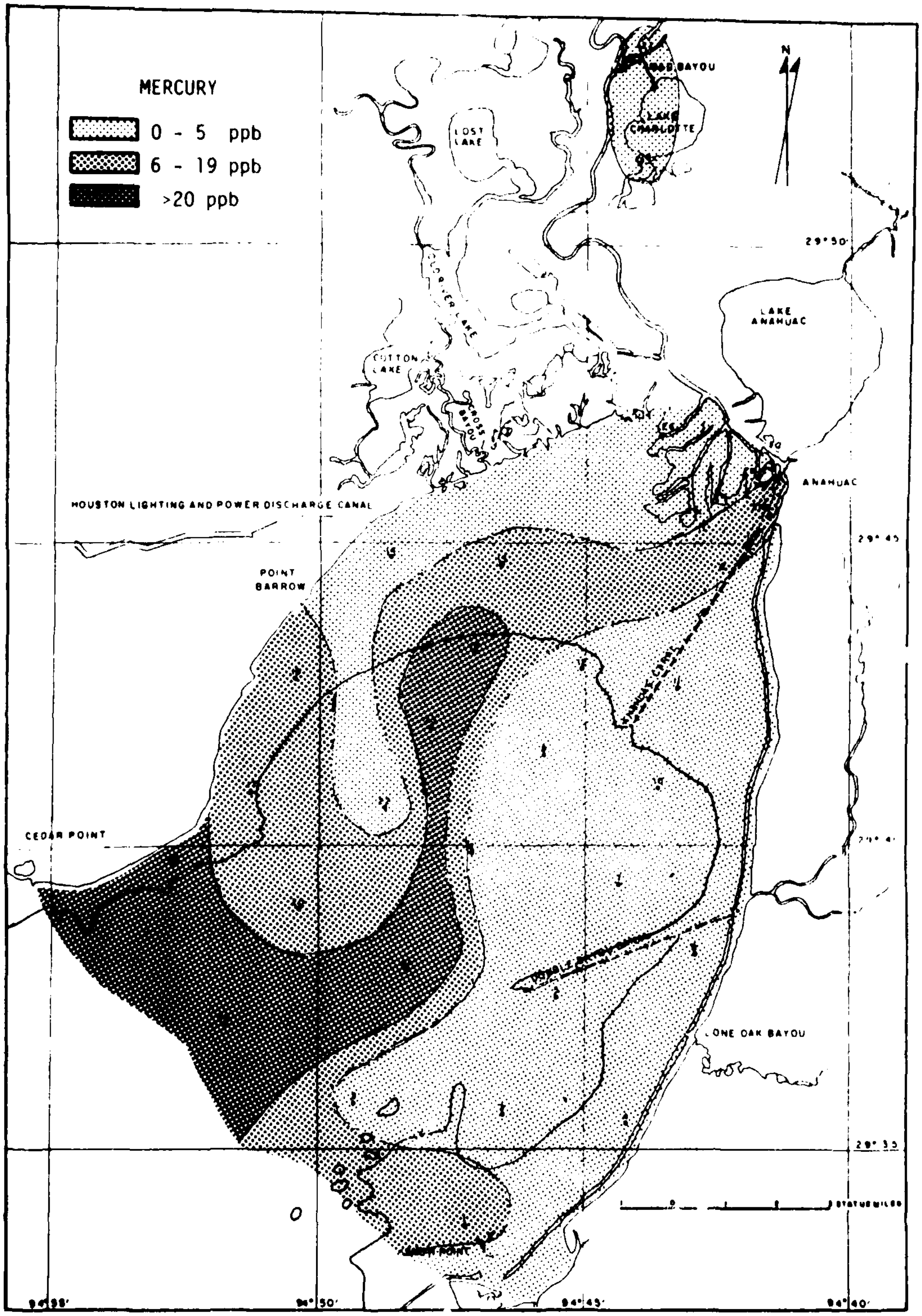
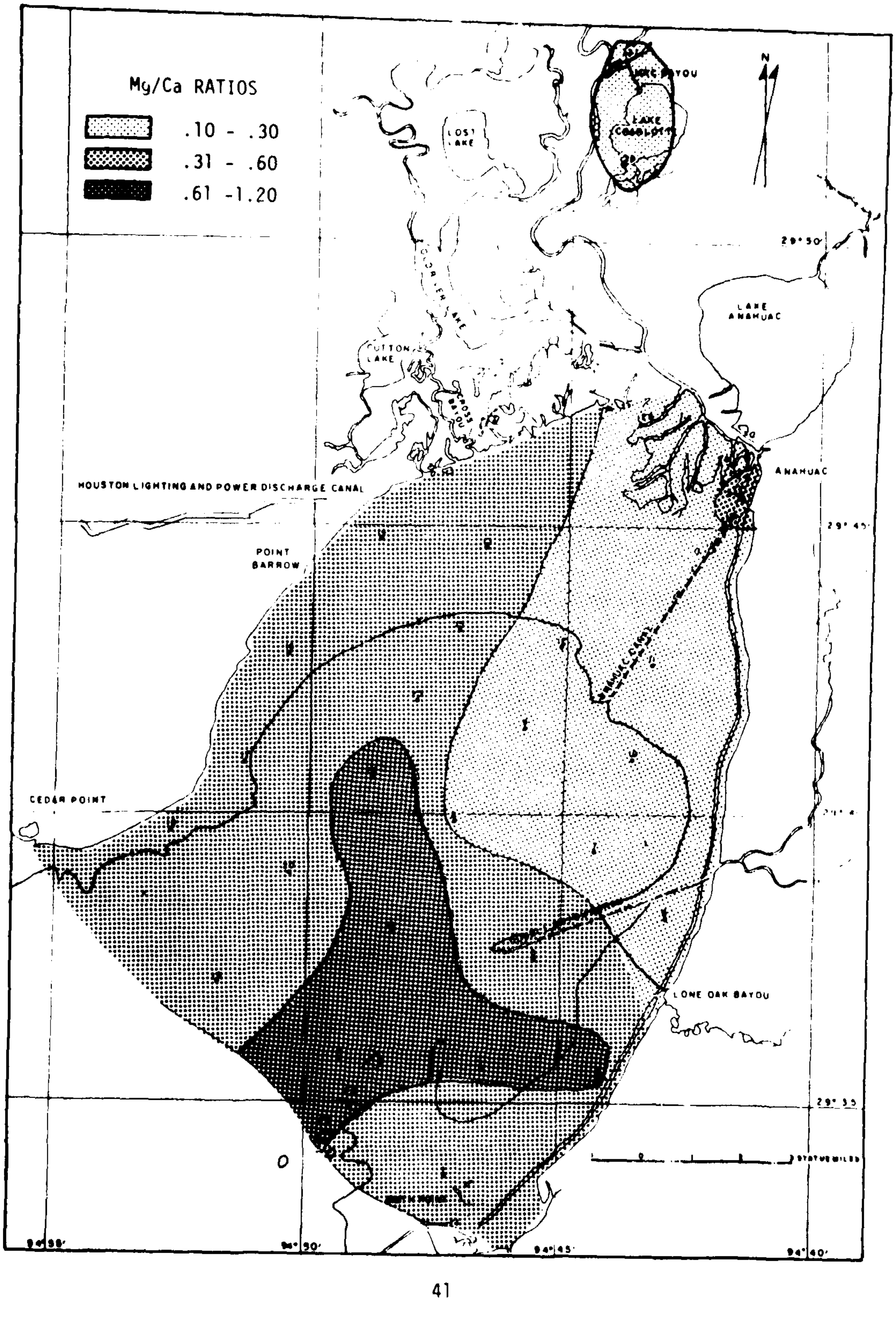

MERCURY
0 - 5 ppb
6 - 19 ppb
>20 ppb
LOST LAKE
LAKE CHARLOTTE
LAKE ANAHUAC
ANAHUAC
COTTON LAKE
HOUSTON LIGHTING AND POWER DISCHARGE CANAL
POINT BARROW
CEDAR POINT
ONE OAK BAYOU
29°50'
29°45'
29°35'
94°50'
94°45'
94°40'

Fig. 10. Distribution of magnesium-calcium ratios (Mg/Ca), Trinity Bay region, Texas.


Mg/Ca RATIOS
.10 - .30
.31 - .60
.61 -1.20
LOST LAKE
LAKE ANAHUAC
ANAHUAC
HOUSTON LIGHTING AND POWER DISCHARGE CANAL
POINT BARROW
CEDAR POINT
LONE OAK BAYOU
29° 50'
29° 45'
29° 35'
94°55'
94°50'
94°45'
94°40'
N

1.02. The ratios for the stations in fresh water up the Trinity River (stations 27 and 28) were also typical of fresh water, which always has an excess of calcium over magnesium, and which may be as high as 20/180 (Kenneth Bird, Professor of Industrial Chemistry, Texas Technical Institute, Waco, Texas, personal communication).

Nutrient Factors

A prime consideration for any study of biological production in an estuary is an investigation of the nutrient budget. Possibly the two most important and perhaps limiting substances to life in an aquatic system are nitrogen and phosphorus, which are needed for the growth of plants that furnish the base of most ecosystem food pyramids. Additional factors that are necessary to both phytoplankton-based and bacterial-based food chains are a ready supply of organic matter, sunlight, and growth substances such as vitamin B_{12}.

Nitrate and Nitrite Ion Concentrations

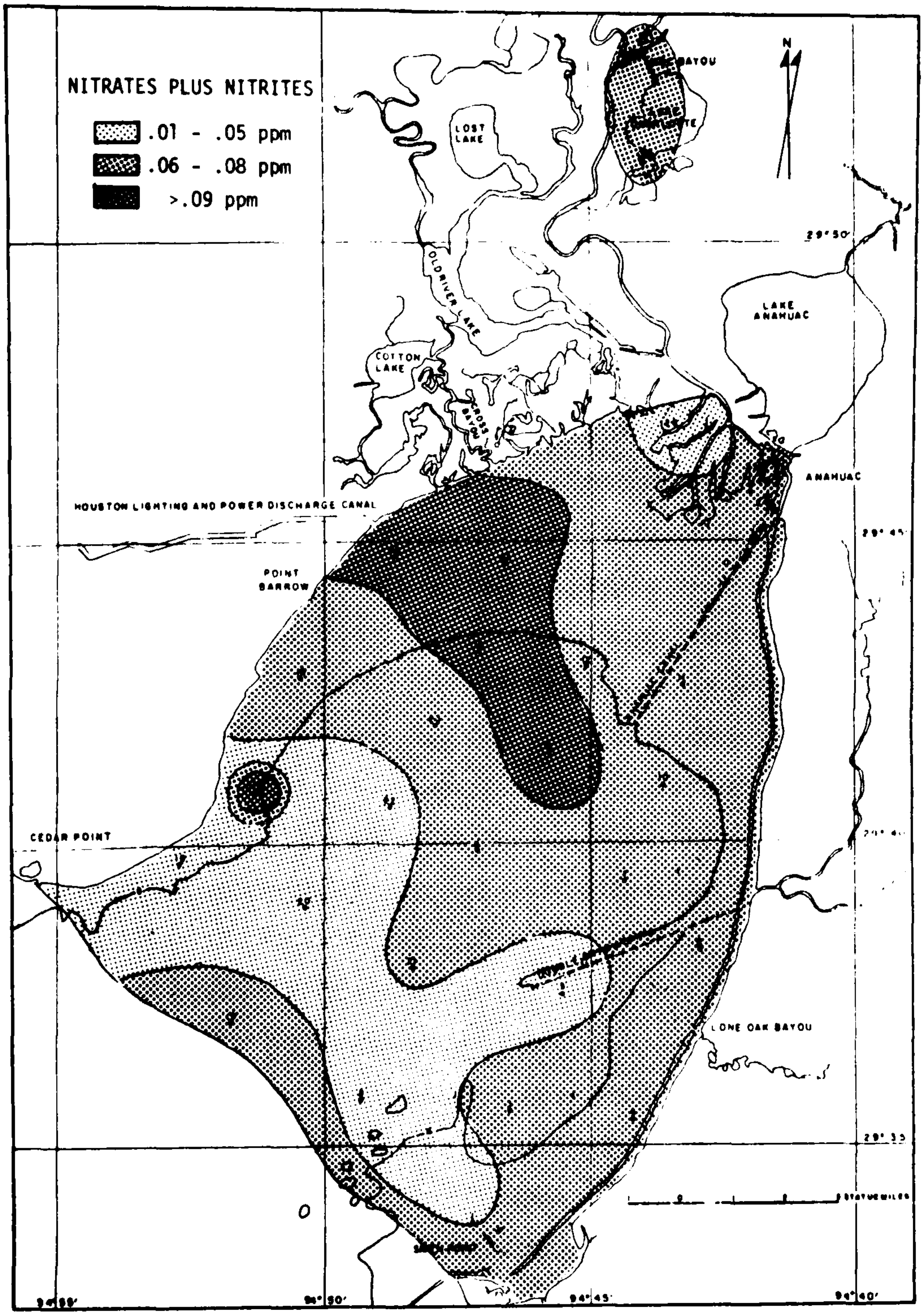
These two ionic forms of nitrogen in water were measured together by using one simple laboratory procedure. In the numerous investigations of this region, every author seems to have used either a different method of analysis or measured different forms of nitrogen. Valid comparisons between data collected during these various studies are therefore rather difficult. Baldauf, *et al.* (1970) measured Kjeldahl nitrogen, which does not include the nitrate and nitrite forms of nitrogen. McLellan (1963) measured inorganic nitrogen, which included the nitrates and nitrites, but excluded ammonia compounds; while Pullen and Trent (1969) measured the total dissolved organic nitrogen. The following investigators measured nitrates only: Dupuy, *et al.* (1970); Hastings and Ireland (1947); Hahl and Ratzlaff (1970, 1972); and the U.S. Geological Survey (1968). Still other authors measured both nitrates and nitrites individually (Parker, *et al.*, 1969).

The combined values for nitrates and nitrites, measured during this study ranged from 0.01 to 0.29 mg/l (Fig. 11, Table I). Values were slightly higher in the upper northwest side of the bay and in a tongue extending outward from the HL&P canal. This could be a result of nitrogen fixation by plants in the marshes of the Trinity Delta (as suggested by Goering and Parker, 1971), excess nitrates from the effluents of the HL&P canal (much higher values were found in 1969 in Cedar Bayou by Culpepper, *et al.*, 1969), or simply that nitrate and nitrite values are always higher in freshwater than in seawater. Dupuy, *et al.* (1970) stated that nitrate values ranged from 0 to 4.6 mg/l in the Trinity River during 1968, while Blakey and Kunze (1971), in a summary of nitrate levels in other Texas streams, gave a range of 0 to 11 mg/l. Hahl and Ratzlaff (1972) and Parker, *et al.* (1969) cited nitrate values in larger rivers as ranging from 0.01 to 0.16 mg/l and 0.02 to 2.3 mg/l respectively. The above levels can be compared with that for total inorganic nitrogen in seawater which is stated as 1 mg/l by McLellan (1963). The minimum concentration of inorganic nitrogen necessary to sustain phytoplankton growth is considered to be 0.3 mg/l (Copeland, and Fruh, 1970).

Phosphate Concentrations

A third nutrient ion considered limiting for phytoplankton populations is phosphate. The element phosphorus was measured as orthophosphate

Fig. 11. Distribution of nitrates plus nitrites ($NO_3^- + NO_2^-$), Trinity Bay region, Texas.


NITRATES PLUS NITRITES
.01 - .05 ppm
.06 - .08 ppm
>.09 ppm
LOST LAKE
OLD RIVER LAKE
COTTON LAKE
LAKE ANAHUAC
ANAHUAC
HOUSTON LIGHTING AND POWER DISCHARGE CANAL
POINT BARROW
CEDAR POINT
LONE OAK BAYOU
29°50'
29°45'
29°35'
94°45'
94°40'
94°50'

during the present study. The area distribution of orthophosphate values in Trinity Bay and the marshes is shown on Figure 12, and the measured values are given in Table I. They ranged from 0.2 to 1.95 mg/l, and were highest on the west side of the bay and lowest in the river. Waters from the lower end of the bay could have been derived from the Houston Ship Channel, or it is possible that all values on the western shore could be related to the fact that the shore is densely populated and receives varying amounts of sewage and detergents from the various housing developments along that shore. Dupuy, *et al.* (1970) cite phosphate levels in the Trinity River at Romayor as ranging from 0.16 to 1.30 mg/l, while Parker, *et al.* (1969) found values in the same reaches of the Brazos and Colorado Rivers to range between 0.01 to 3.8 mg/l. Bay values appear to differ little from those cited above, ranging from 0 to 1.47 mg/l, according to Pullen, Trent, and Adams (1971). On the other hand, total phosphorus values from the same stations were found to range from 3.34 to 6.69 mg/l (Pullen, and Trent, 1969). Espey, *et al.* (1971) stated that phosphorus levels in the bay have been increasing the last six years, reaching a level of around 2 mg/l. Again, the higher values in the vicinity of the HL&P canal could have resulted from Cedar Bayou waters being drawn into Trinity Bay. Our earlier study of Cedar Bayou revealed extremely high phosphate levels in the upper portion of the bayou. These values must be contrasted with the normal amount of total phosphorus in seawater which is 0.06 mg/l (McLellan, 1963). Pullen, *et al.* (1971) and Gloyna and Malina (1964) stated that levels of phosphorus decreased from the upper bay to the lower bay. We observed higher values of phosphate in the lower bay than in the upper bay. On the other hand, any comparisons between published values and ours must be carefully weighed, as we measured orthophosphate and others may have measured other forms of phosphate. Hooper (1969) indicated that several problems remain to be solved before orthophosphate can be used as a good indicator of nutrient phosphorus levels. It should be noted, however, that the same methods of phosphate detection were used by Culpepper, *et al.* (1969), Parker, *et al.* (1969), and in the present study.

An ideal ratio of nitrogen to phosphorus for best phytoplankton growth is considered to be 10:1 (Copeland, and Fruh, 1970). Examination of Figures 11 and 12 shows that phosphate values are much in excess of nitrate-nitrite values, indicating that the present phytoplankton production might be influenced by such a ratio.

Total Organic Carbon Levels

Another parameter important to the study of primary productivity is Total Organic Carbon (TOC), which is the amount of carbon assimilated into plant or animal matter per unit of volume and is a standard indicator of biological activity in water and sediments. The total amount of carbon in each water sample was determined and further analyzed as to the component inorganic (from $CaCO_3$ or shells) and organic percentages. The average percentages of both inorganic and organic components for all except five stations were calculated from data in Table I. The averages for these 23 stations were 10.9% organic carbon and 89.1% inorganic carbon. Similar values were obtained from Puget Sound, Washington, with 11.3% organic carbon and 88.7% inorganic carbon (Sverdrup, *et al.*, 1942). On the other hand, the five samples from stations 15 through 19 averaged 65.4% organic

Fig. 12. Distribution of orthophosphate (PO_4^{-3}), Trinity Bay region, Texas.

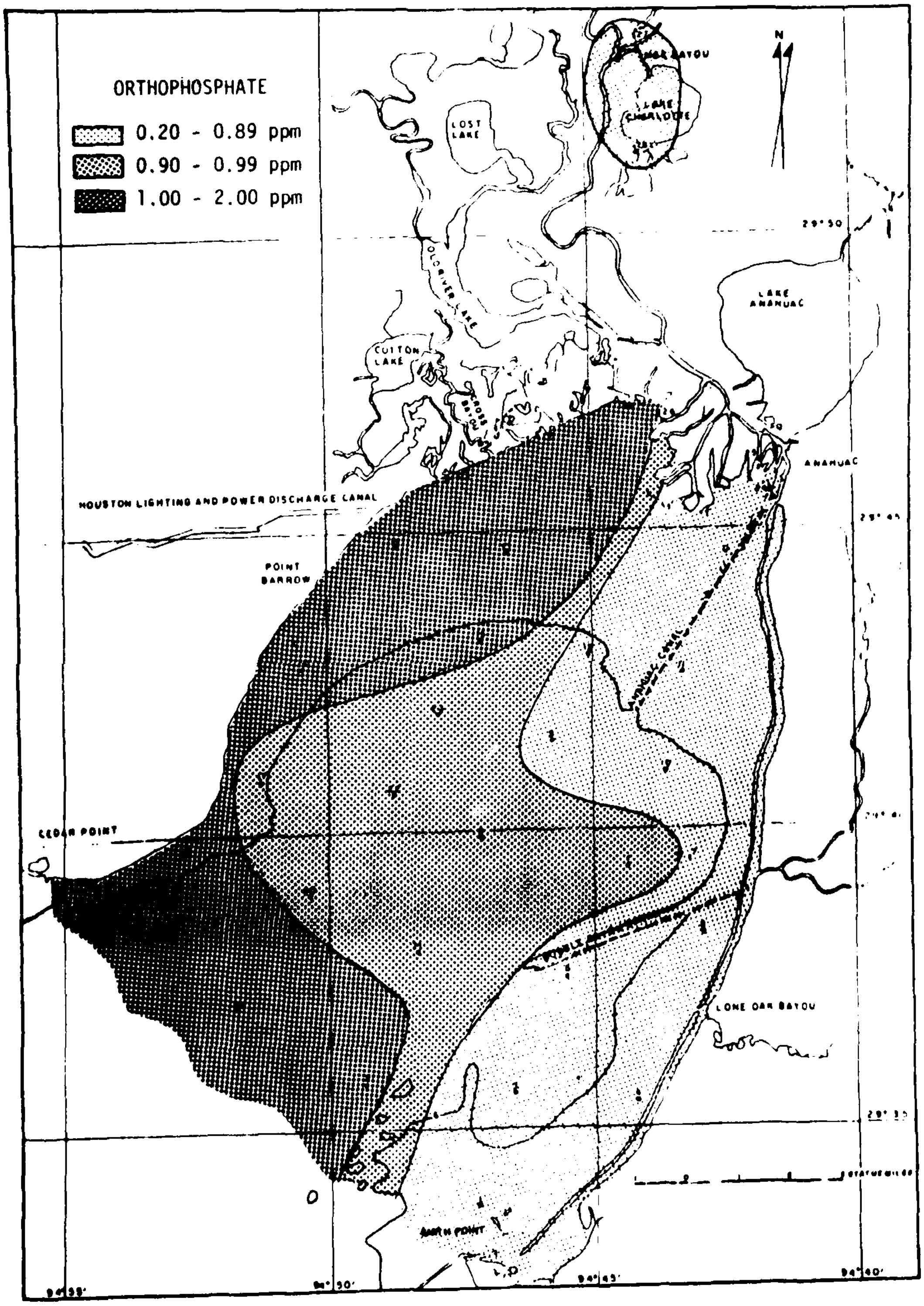
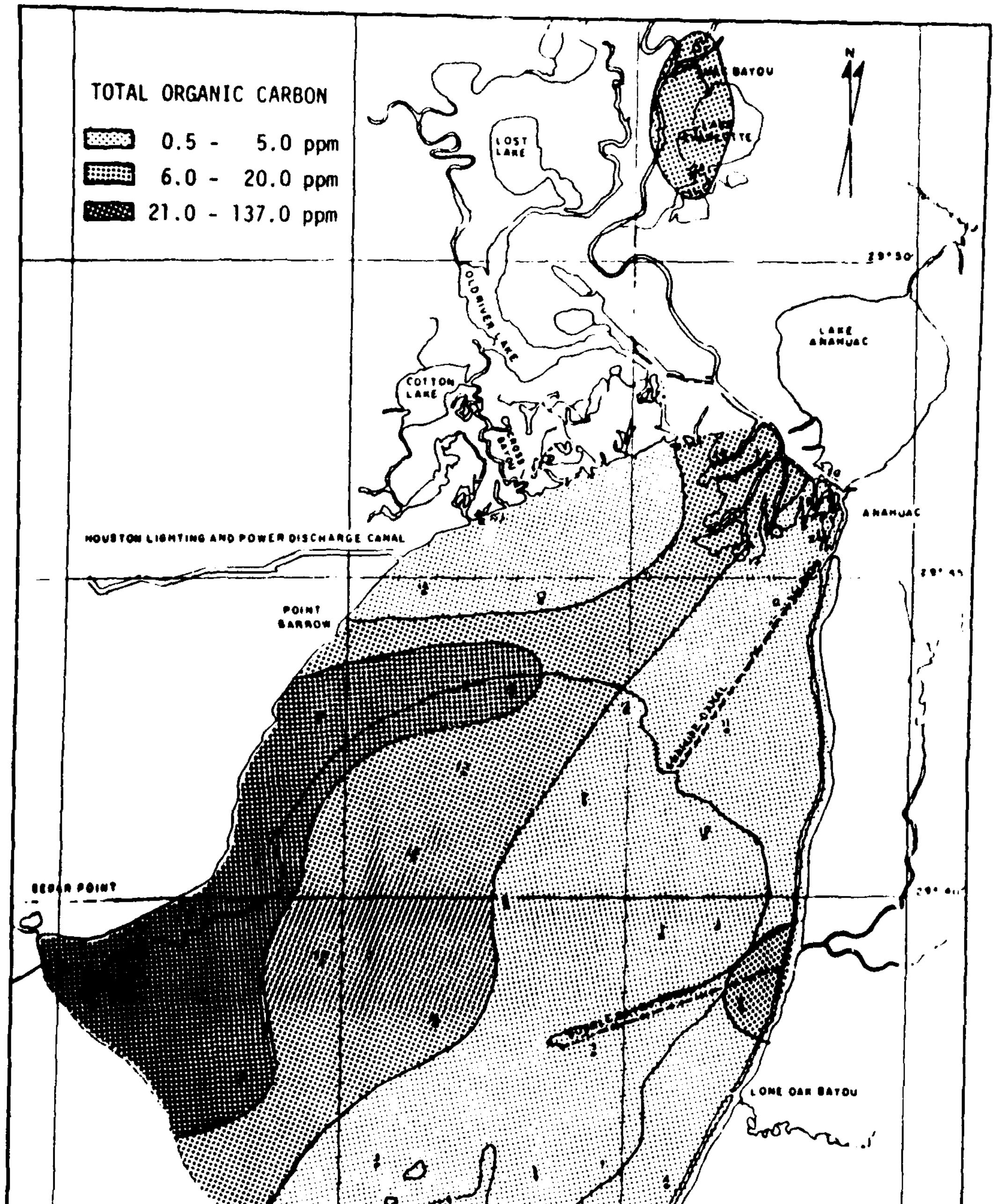

ORTHOPHOSPHATE
0.20 - 0.89 ppm
0.90 - 0.99 ppm
1.00 - 2.00 ppm
LOST LAKE
LAKE CHARLOTTE
LAKE ANAHUAC
ANAHUAC
COTTON LAKE
OLD RIVER LAKE
HOUSTON LIGHTING AND POWER DISCHARGE CANAL
POINT BARROW
CEDAR POINT
LONE OAK BAYOU
N
29°50'
29°35'
94°50'
94°45'
94°40'

Fig. 13. Distribution of total organic carbon (TOC), Trinity Bay region, Texas.


TOTAL ORGANIC CARBON
0.5 - 5.0 ppm
6.0 - 20.0 ppm
21.0 - 137.0 ppm
LOST LAKE
OLD RIVER LAKE
COTTON LAKE
LAKE ANAHUAC
ANAHUAC
HOUSTON LIGHTING AND POWER DISCHARGE CANAL
POINT BARROW
LONE OAK BAYOU

and 34.6% inorganic carbon, an almost complete reversal of abundances. The TOC values are mapped on Figure 13 where it can be seen that the five high values are concentrated in a tongue along the southwestern shore of the bay. Lowest values were measured from waters taken in the quiet eddy in the northwestern side of the bay and along most of the eastern side. Low values could be attributed to lower turbidity from the more protected or less agitated waters, while the higher levels might originate from the Houston Ship Channel or from numerous outfalls emanating from the more populated side of the bay.

Carbon is involved in the carbonate cycle in seawater and in the carbon uptake and hydrocarbon synthesis by green plants, in addition to being utilized in organic synthesis and degradation processes by bacteria. High TOC values can either be indicative of excess input of organic material from human activities, high biological activity, or low BOD's (biochemical oxygen demand) and consequent reduced oxidation of organic matter. TOC is often a principal indicator of water quality; and in the case of the present set of samples, TOC's are well within the range of values for good water.

Biological Factors

Bacterial Populations

Bacterial counts were made for both bottom water and sediments throughout the study area (Figs. 14 and 15). Bacterial populations in Trinity Bay are of almost inestimable importance in the maintenance of a smoothly operating ecosystem. Large populations and high diversity of bacteria are needed to degrade the immense amounts of organic matter, so typical of Texas bays (Parker, *et al.*, 1969). In addition, it is suspected that these large populations of microflora provide the food base for many invertebrates. In fact, it can be further postulated that bacteria may form the primary productivity base for most Texas bay ecosystems, as turbidity is so high that there is not enough sun's energy to sustain the photosynthetic activity of high phytoplankton populations (Parker, Scott, Berry, and Baker, manuscript).

Bacterial counts from the present sampling program ranged from 6.4×10^4 cells/ml to 1.03×10^{10} cells/ml (Table I). Similar counts were made (using the same techniques) for marine environments in Puget Sound, Washington, which yielded 1×10^3 to 1×10^9 cells/ml (Watson, Smith, Ehrsam, Parker, Blanton, Solomon, and Blanton, 1971). Somewhat lower counts (4×10^5 to 8.6×10^7 cells/ml) were obtained from two south Texas bays after the devastating effects of Hurricane Beulah (Berry, 1969). Even lower counts, ranging from 0 to 1×10^6 cells/ml, were made on sediments from the Brazos and Colorado estuaries by Parker, *et al.* (1969) and in Cedar Bayou by Culpepper, *et al.* (1969). The latter three sets of counts were made by direct count and plating out only and may not be strictly comparable to the Puget Sound and Trinity Bay counts. Oppenheimer (1952) observed extremely high counts in some of the south Texas bays. He found populations of bacteria in certain bay sediments to range as high as 1×10^{14} cells/ml, possibly the highest concentrations on record. According to various textbooks in microbial ecology, populations over 1×10^4 cells/ml become a significant part of any aquatic ecosystem and populations over 1×10^6 are likely to exert a considerable control over the ecosystem.

Fig. 14. Distribution of bacterial counts, cells/ml, for bottom water samples, Trinity Bay region, Texas.

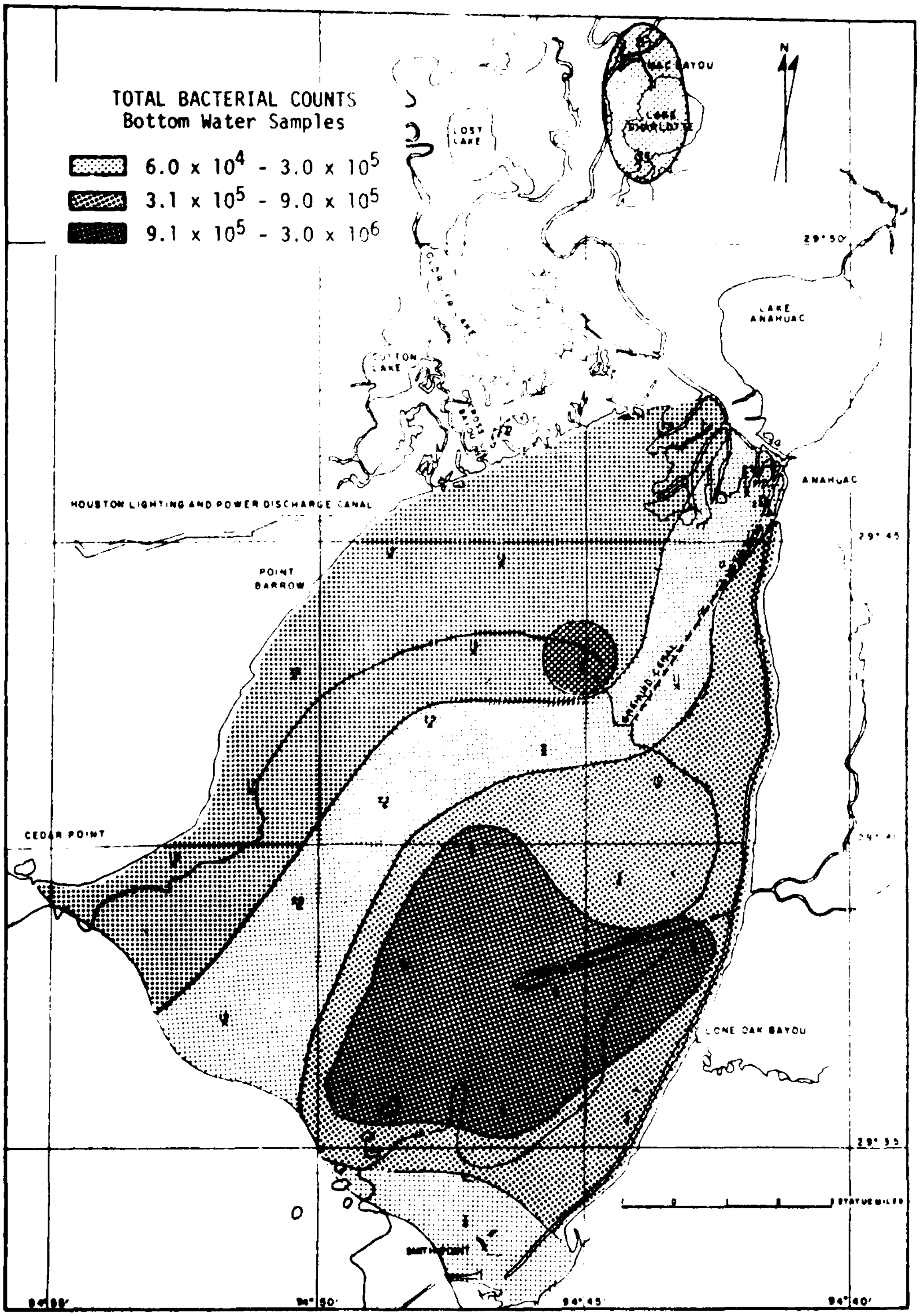
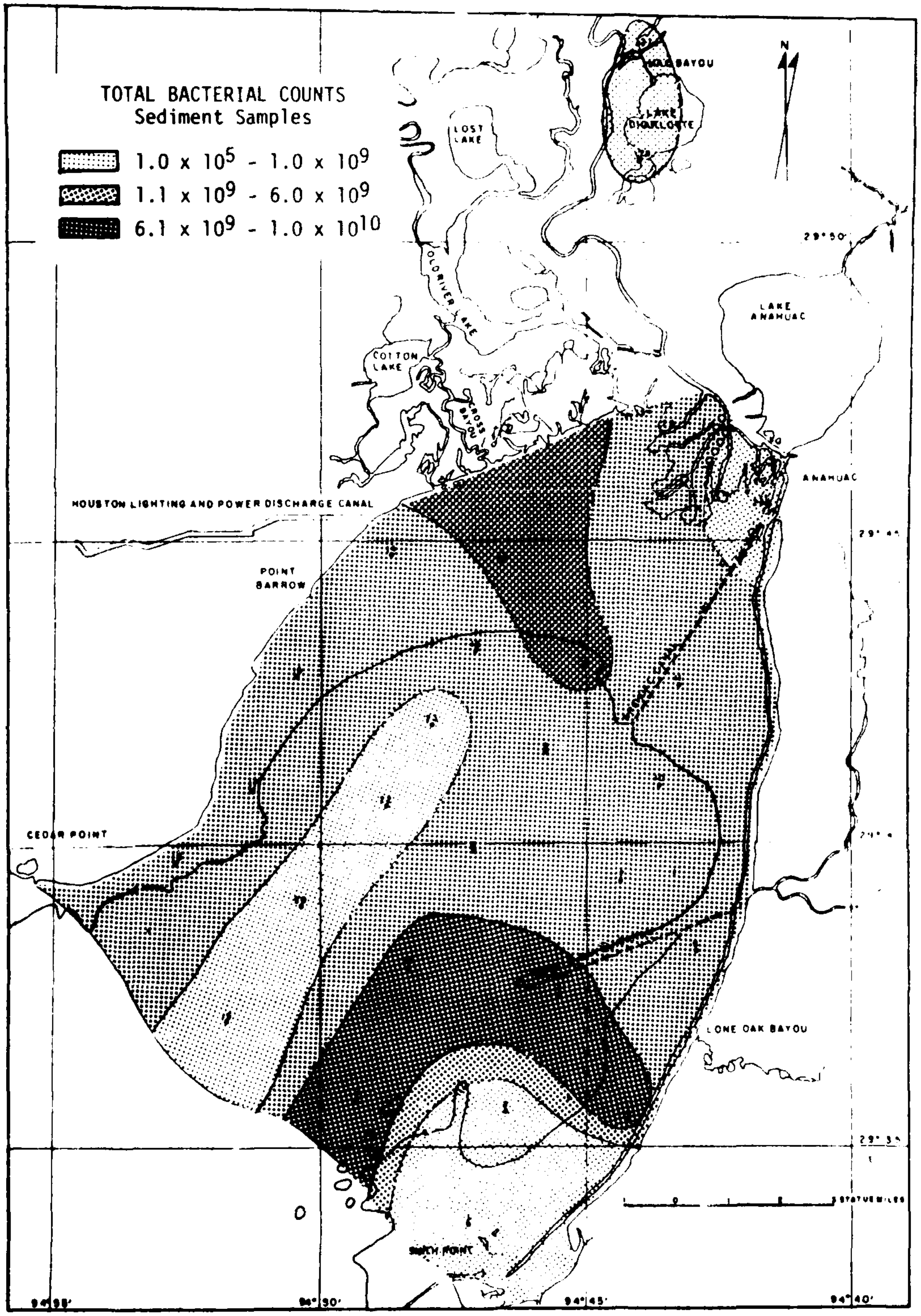

TOTAL BACTERIAL COUNTS
Bottom Water Samples
6.0 x 10^4 - 3.0 x 10^5
3.1 x 10^5 - 9.0 x 10^5
9.1 x 10^5 - 3.0 x 10^6
LOST LAKE
LAKE CHARLOTTE
LAKE ANAHUAC
ANAHUAC
COTTON LAKE
HOUSTON LIGHTING AND POWER DISCHARGE CANAL
POINT BARROW
CEDAR POINT
LONE OAK BAYOU
29°50'
29°45'
29°35'
94°50'
94°45'
94°40'
STATUTE MILES
N

Fig. 15. Distribution of bacterial counts, cells/ml, for sediment samples, Trinity Bay region, Texas.



TOTAL BACTERIAL COUNTS
Sediment Samples
1.0 x 10^5 - 1.0 x 10^9
1.1 x 10^9 - 6.0 x 10^9
6.1 x 10^9 - 1.0 x 10^10
LOST LAKE
LAKE ANAHUAC
COTTON LAKE
OLD RIVER LAKE
HOUSTON LIGHTING AND POWER DISCHARGE CANAL
ANAHUAC
POINT BARROW
CEDAR POINT
LONE OAK BAYOU
29°50'
94°45'
94°40'

Bacterial populations in our water samples (Table I) ranged from 1.3×10^5 to 2.9×10^6, unusually high for water alone. The plot of these values on Figure 14 shows lowest values in the river and in what could be considered as a channel through the center of the bay to the entrance. Highest values were found in the southeastern section of the bay, possibly reflecting the presence of gulf or more marine water. Population levels and diversity of bacteria in estuarine waters may indicate environmental stability (Parker, *et al.*, 1969). If so, then the southeastern part of Trinity Bay may well represent the more stable greater Galveston Bay water. What is most important, however, is that these high water counts of bacteria can seed exceedingly high populations, needed to degrade the large amounts of organic matter on the bottom.

Benthic bacterial counts from surficial sediments are almost twice as high as those derived from bottom water samples; and what is more significant, they are three to four orders of magnitude greater than those found in the sediments of other Texas bays and estuaries. These population figures are shown in Table I, and mapped on Figure 15. Note the high benthic numbers off the HL&P outfall and in a patch near the southeastern corner of the bay (Fig. 15). High benthic populations off the outfall may relate to the high TOC derived from Cedar Bayou and Houston Ship Channel waters. On the other hand, high values in this part of the bay may represent more stable bottom conditions.

These overall high, water and sediment, bacterial populations lend support to our earlier premise that the production base of Trinity Bay food chains may well be bacterial degradation and recycling of a large organic matter base, rather than nannoplankton and plant production.

Comparatively little sunlight reaches the bottom of this and other Texas bays, yet there is a tremendously high production of total organic matter. Shrimp, oyster, crab, and fish production is one of the highest of any estuarine area in the United States (Parker and Blanton, 1970). The majority of these larger organisms are scavengers or detritus feeders. They are rather shortlived and have high reproductive potentials, facts which suggest a major recycling of organic matter through a food chain which exists largely without plants. What then furnishes food for the smallest animals? Bacteria could not only be a food source for small benthic organisms, but may break down organic matter into food-sized particles for these organisms. If this type of ecosystem (based on total recycling of organic matter) is typical of Trinity Bay, the amount of runoff derived from Trinity River may be relatively unimportant, so far as contributing nutrients for bay plant production.

Plankton Populations

Plankton samples were collected at 11 stations in the bay. Interpretation of these samples is limited because quantitative collection of the samples in the field was impossible. The laboratory analyses, as to populations and diversity, can therefore only be discussed in general terms. Results of these plankton counts, as numbers of plants and animals, are given in Table II. The diatoms of the Genus *Coscinodiscus*, with an estimated population of 0.37 to 14.98 organisms/liter at the various stations, were the most abundant phytoplankters in these samples. This genus is also the commonest one in other Texas bays (Parker and Blanton, 1970).

TABLE II

PLANKTON POPULATIONS PER LITER OF WATER

AT SELECTED STATIONS

Station	Number of Organisms Phytoplankton	Zooplankton
1	3.57	.88
2	9.50	3.54
3	3.34	5.28
4	7.52	1.15
5	6.02	3.80
6	4.72	2.79
7	8.65	13.69
8	1.93	4.44
12	3.92	3.82
13	29.97	16.27
18	.75	.91
MEAN	7.26	5.14

Total zooplankton populations, dominated by copepods, ranged from 0.88 to 16.27 organisms/liter with zoeal larvae of various crustacean species forming only a small part of the zooplankton population. The numbers of phytoplankton and zooplankton per liter found by us were much higher in August of 1972 than they were in July 1969 (Copeland, and Fruh, 1970). The salinities of 1-9 $^{o}/oo$ reported by Copeland and Fruh (1970) were much lower than those observed recently in this study (11.8-18.3 $^{o}/oo$) and it is possible that the higher salinities might result in greater numbers of marine phytoplankton and zooplankton. Nevertheless, high plankton populations have never characterized upper Texas coastal bays, and these counts are no exception. Tremendously high plankton counts have been observed in South Texas bays, but salinities are higher and waters shallower and clearer. For this reason, we feel that the maintenance of high plankton populations in Trinity Bay, through river discharge control, is not as important to the functioning of these ecosystems as one would suppose.

Benthic Invertebrate Populations

A quantitative survey of benthic invertebrate populations was made of Trinity Bay bottoms, even though these organisms are not part of the primary production base of the food chain. On the other hand, because of the distinctive nature of this special ecosystem which may be based more on the bacterial degradation of organic matter than on photosynthetic production, the smaller benthic organisms could be closer to the food base than in other bay type ecosystems. The number of benthic organisms is a parameter which has been used by C.E.M. personnel in most of the other bays along the Gulf coast during the past 10 years, thus a competent yardstick for standing crop was available and could be used as a standard for determining a major part of the biological production.

Counts of the numbers of individuals of each major taxon (copepods, snails, clams, polychaetes, etc.) for each size fraction were made for all of the 1/25 m^2 grab samples. Total sample counts also were converted to numbers per square meter (Table I). The 1/25 m^2 populations were plotted areally in Figure 16, using a log-scale breakdown for population levels. It can be noted that the largest populations are associated with shell bottom (stations 1 and 21) and within a few hundred yards of the shoreline (stations 4, 13, 16, 17, and 24), where sediments are classified as sand-silt-clay (Fig. 17). Total numbers of organisms/m^2 from the shell bottoms averaged about 142,000/m^2, and the average for the bay margin areas is about 38,500/m^2. Low standing crops were associated with the Houston Lighting and Power Company outfall and the finer sediment covered bottom of the center of the bay (stations 2, 3, 5, 8, 9, and 14). The lowest standing crop averaged only 1,700 animals per m^2 and were found in silty clay or clayey silt (Fig. 17). The rest of the samples taken from the predominately clayey silt and clayey sand sediments averaged 9,170/m^2. As the map (Fig. 16) indicates, there are orders of magnitude decreases in populations from the shore to the center of the bay.

The patterns of invertebrate populations are similar to those found in other Texas bays (Parker, 1959, 1960, and Parker and Blanton, 1970), with the highest populations being found in poorly sorted, sandy to silty sand sediments. The more loosely compacted the sediments, the more interstitial spaces are available for animal life. Fine detrital silty

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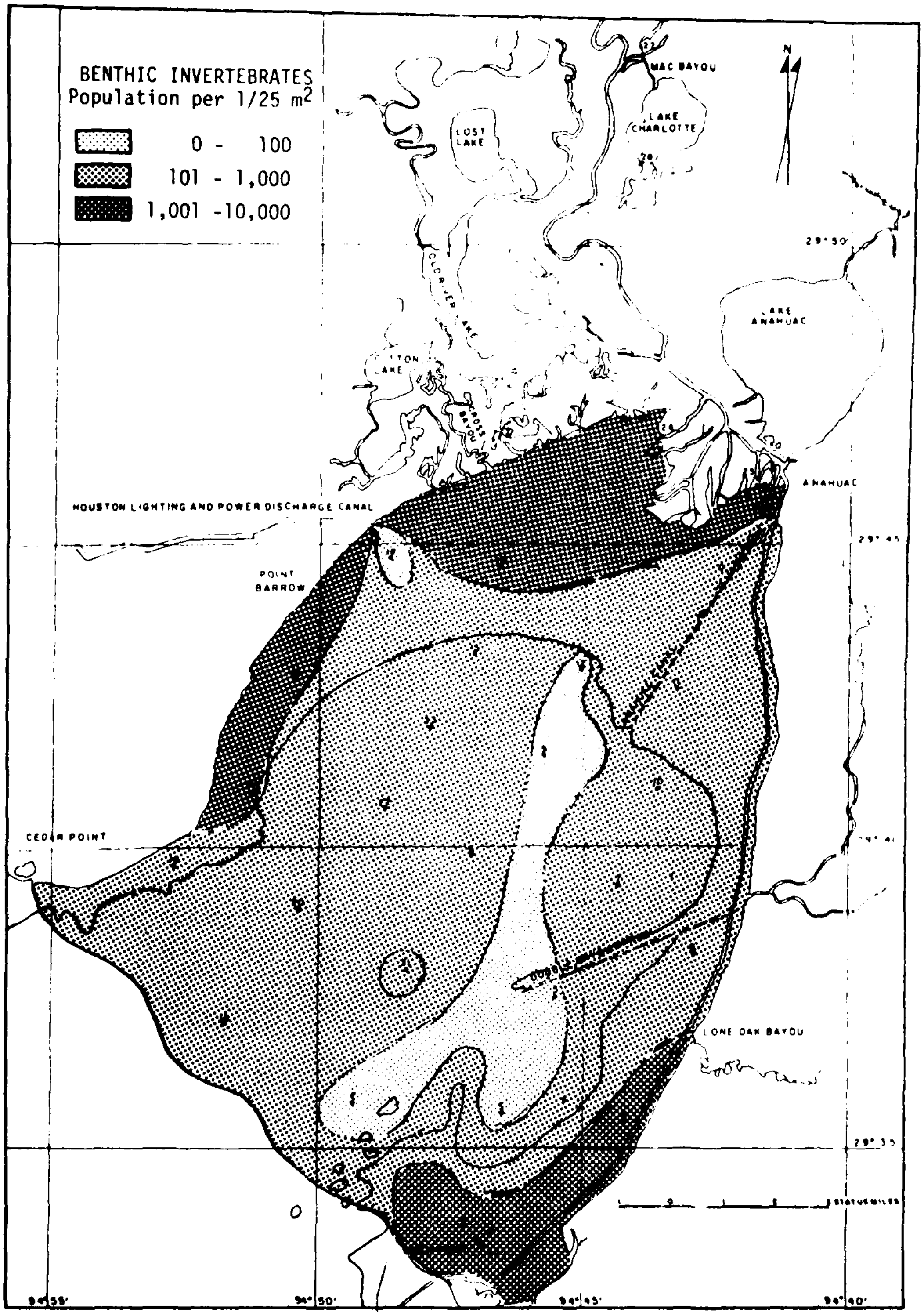
Total populations of invertebrates (larger than 250 microns) are greater in Trinity Bay than in other Texas bays. Depending upon sediment type, the Trinity Bay benthos averages ranged from 1,700 to 140,000 animals/m^2; the average for the bay as a whole being 25,000 animals/m^2. Only the grass flats in Aransas Bay and Redfish Bay in the Coastal Bend region yielded higher average numbers of animals per unit area, 20,000 to 30,000/m^2 respectively (Parker, and Blanton, 1970). Other average populations for Texas bays include: 800/m^2 for Corpus Christi Bay; 3,000/m^2 for Copano Bay; 5,000/m^2 for Nueces Bay; 6,000/m^2 for Lavaca Bay; and 9,000/m^2 for clay bottoms in Aransas Bay (Parker, and Blanton, 1970). Lower counts were obtained from a normal marine environment (Puget Sound) of 600 to 12,000 animals/m^2, using the same methods. A high energy environment in slightly lower salinities on the East coast yielded numbers (10,000 to 110,000 animals/m^2) comparable to those of Trinity Bay (Parker, and Blanton, 1970). The highest numbers of animals (well over 500,000 animals/m^2) attained to date with the present sampling techniques were from the west Mississippi Delta region after an oil spill (unpublished manuscript, C.E.M. report for Environmental Protection Agency, 1971).

Benthic Diversity

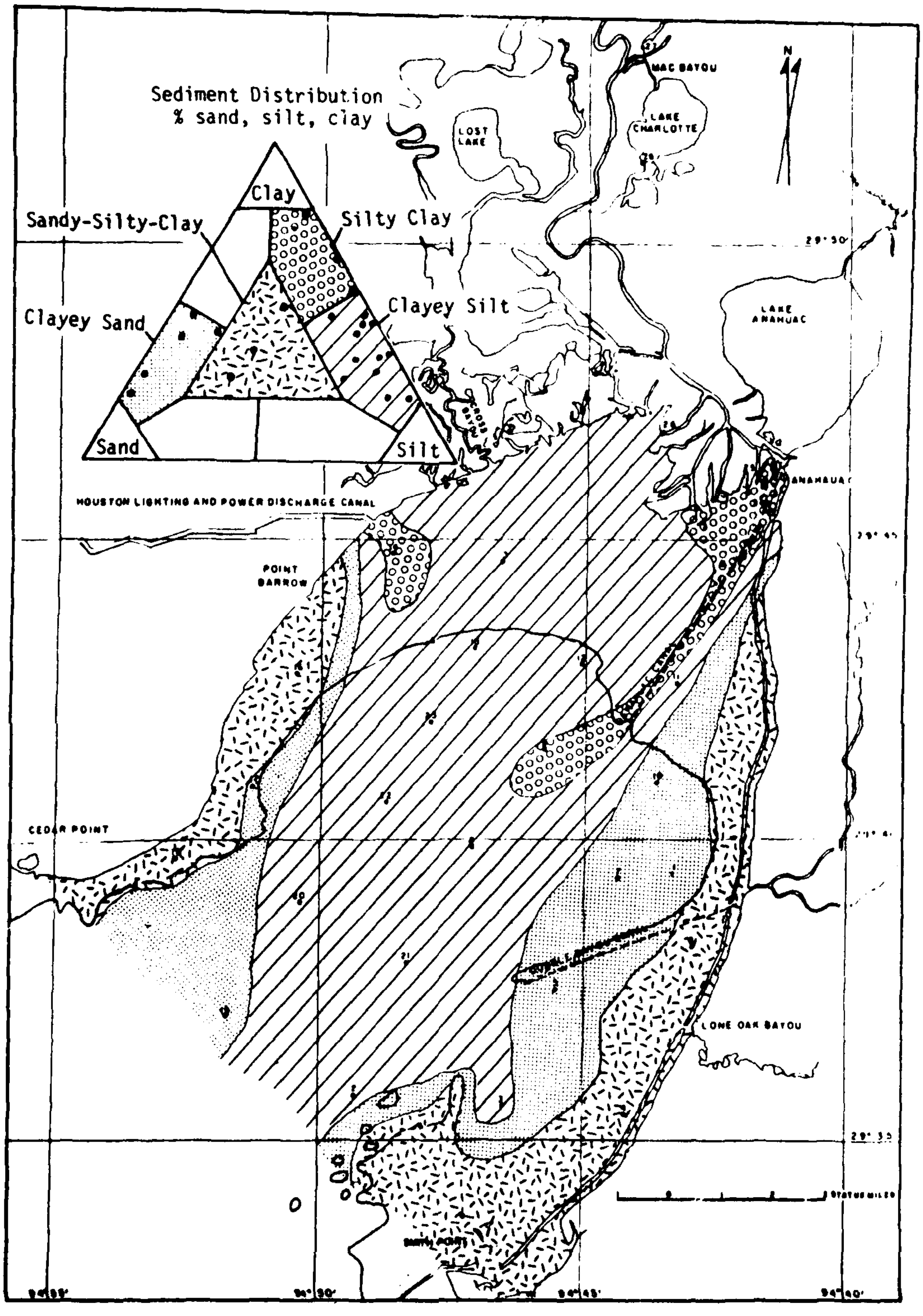
The large number of benthic invertebrates living in Trinity Bay, as revealed by our studies, indicates that the bay is an excellent habitat for

Fig. 16. Distribution of benthic invertebrates populations per 1/25 m^2, Trinity Bay region, Texas.



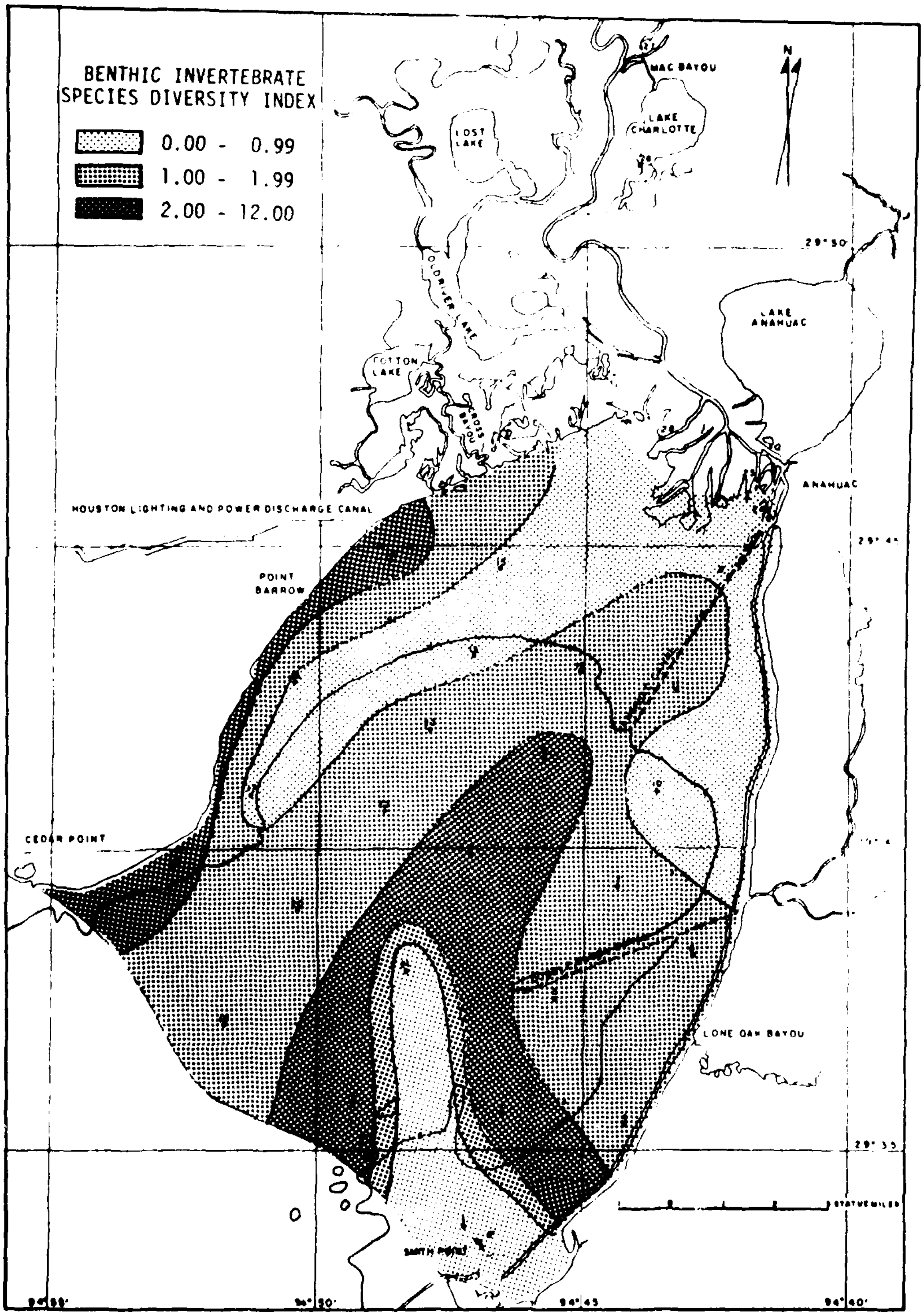
BENTHIC INVERTEBRATES
Population per 1/25 m²
0 - 100
101 - 1,000
1,001 -10,000
MAC BAYOU
LAKE CHARLOTTE
LOST LAKE
LAKE ANAHUAC
ANAHUAC
HOUSTON LIGHTING AND POWER DISCHARGE CANAL
POINT BARROW
CEDAR POINT
LONE OAK BAYOU
29°50'
29°45'
29°35'
94°55'
94°50'
94°45'
94°40'

Fig. 17. Distribution of sediments, according to Coastal Ecosystems Management, Inc. data, Trinity Bay region, Texas.



Sediment Distribution
% sand, silt, clay
Clay
Sandy-Silty-Clay
Silty Clay
Clayey Silt
Clayey Sand
Sand
Silt
MAC BAYOU
LOST LAKE
LAKE CHARLOTTE
LAKE ANAHUAC
HOUSTON LIGHTING AND POWER DISCHARGE CANAL
POINT BARROW
CEDAR POINT
LONE OAK BAYOU
STATUTE MILES

Fig. 18. Distribution of benthic invertebrate species diversities (DI), Trinity Bay region, Texas.


BENTHIC INVERTEBRATE
SPECIES DIVERSITY INDEX
0.00 - 0.99
1.00 - 1.99
2.00 - 12.00
MAC BAYOU
LAKE CHARLOTTE
LOST LAKE
N
LAKE ANAHUAC
COTTON LAKE
ANAHUAC
HOUSTON LIGHTING AND POWER DISCHARGE CANAL
POINT BARROW
CEDAR POINT
LONE OAK BAYOU
STATUTE MILES

these animals. They should furnish a good food base for larger nektonic organisms; such as, shrimp, crabs, and fish. A better index of environmental quality, than number alone, is the diversity of organisms, often expressed as the Diversity Index (DI). A number of diversity indices have been proposed to indicate water quality and have been summarized in an unpublished report for ALCOA (Blanton, Culpepper, Bischoff, Smith, and Blanton, 1971). Rather than become involved in long and laborious calculations needed for some of the formulae suggested as a means for determining true diversity, we have settled on a very simple diversity index formula,

$$DI = \frac{\text{number of taxa}}{\text{number of individuals}} \times 100$$

This simple index is of value to C.E.M. because it has been used for all of our other studies of a similar nature on the Texas coast and gives us a frame of reference to use for comparison between known and unknown disturbed and normal estuaries.

A plot of our calculated diversity indices is shown on Figure 18, and the values are displayed on Table I. One reason our diversity indices may be of a more objective nature is that a single set of taxa (86 in number and easily identifiable to most biologists) is used in the breakdown of kinds of organisms. No attempt was made to identify all animals to species, but it was possible to give exact numbers of animals in each of the larger identifiable groups; such as, nematodes, copepods, ostracods, etc. The patterns on Figure 18 reflect a general increase of diversity from the highly unstable river estuary to the more stable waters in the mouth of the bay. Higher diversity was characteristic of the shelly bottoms and of coarser sediments near the margins of the bay. According to Slobodkin and Sanders (1969) and further substantiated by Parker and Blanton (1970), high diversity is a function of the stability and predictability of environments in the normal ranges of environmental factors, while low diversity is characteristic of areas with extreme variability and unpredictability in the extreme ranges of environmental factors. The environments at the river mouth are both unstable and unpredictable as are those in the area where the Gulf waters from the Houston Ship Channel meet river waters at the mouth of the bay. The most predictable and stable areas are in the deep center of Trinity Bay which has the highest diversity index. The few very high indices are misleading in that they result from small numbers of individuals divided by only one or two taxa, rather than being from a true high diversity. According to Wilhm and Dorris (1968), a diversity index less than one indicates heavy pollution, an index between one and three indicates moderate stress, and indices greater than three denote high water quality. Using those criteria alone, Trinity Bay could be considered as under moderate to heavy stress. Of the 24 stations at which diversity was measured, eight had an average DI of 0.5, ten stations had DI's that averaged 1.4, and the six highest stations had an average DI of 6.5 (Fig. 18). Assuming that our calculations of diversity are equivalent to those measured by Wilhm and Dorris (1968), it is not necessarily true that the low values can be attributed to pollution. Stress on an ecosystem is not always the result of man's disturbance. Far greater stresses are imposed by nature in the form of hurricanes, floods, and droughts (Parker, and Blanton, 1970). As mentioned previously, the areas identified by the lowest DI's are naturally stressed areas through greatest variations in environmental factors. An exception to this is the area encompassing the two stations in the lower end of the bay.

Sedimentary Facies

As we have seen in the section dealing with benthic animals, sediment composition exerts a considerable control on the distribution of bottom-living animals. The distribution of sediments is also a vital factor concerned with circulation and projected changes in circulation as a result of reduced or increased river discharge. A baseline or present distribution map of Trinity Bay sediments is needed to assay future shifts in sedimentary patterns. Although relatively few sediment samples were collected (27), they serve to adequately describe the general patterns of sand, silt, and clay distribution (Fig. 17).

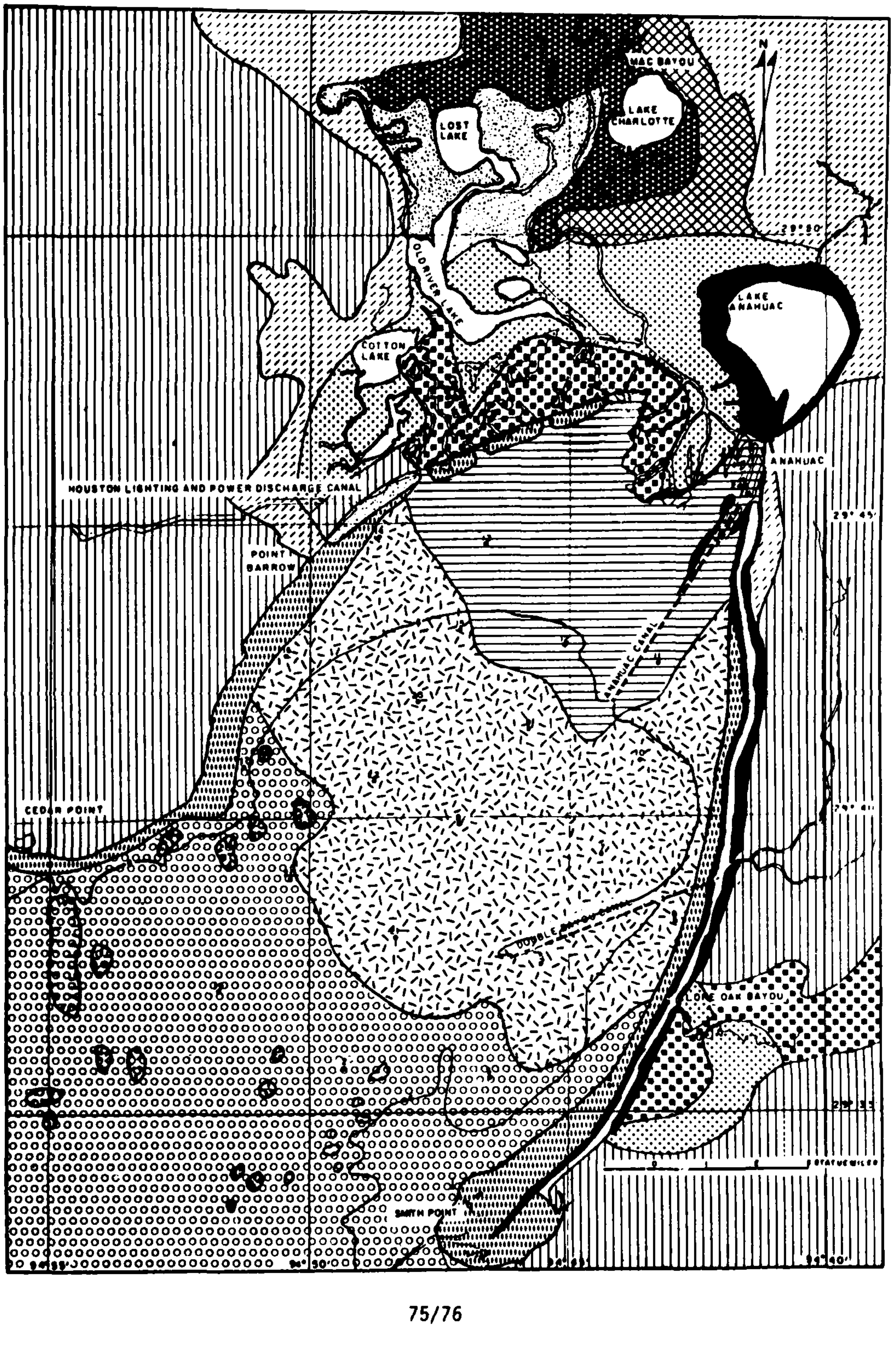
Note that names have been applied to the various combinations of these sediment sizes, as derived from the plots of the percentages of sand, silt, and clay on the triangular (3 dimensional) plotting diagram (Shepard, 1954). Each of the three apices represent 100% of one of the fractions and where the bisection of the apex meets the opposite side, the percentage is zero. If the predominant sediment is sand and the lesser amount is clay (more than 25%) the sediment is called clayey sand. Only four kinds of sediments exist in Trinity Bay: sandy-silty-clay (equal parts of each), reworked by wave action at the margins of the bay in less than six feet of water; clayey sand, distributed by gravity, wave-action, and currents, is the next deepest sediment; clayey silt, making up most of the bay basin; and silty clay, produced through gravity settling of source material, at the mouths of both the Trinity River and the HL&P outfall. This is almost a classic pattern of bay sedimentation, with coarse sediments along the shore and finer sediments in the bay center. This pattern could shift considerably if the source of fine sediments were to be cut off. Deposition of fine materials would cease and the erosion of the delta and shore sands would begin. Eventually, the clays would be winnowed out and distributed elsewhere in the Galveston Bay system, leaving coarser, and possibly more productive, sediments behind.

A generalized description of sedimentary and faunal facies, based on a few samples taken in the early 1950's, was presented by Parker (1960). He recognized marshes, a river-influenced enclosed bay habitat, bay margin and bay center habitats, and an oyster reef community in Trinity Bay. During that early reconnaissance study, this author remembers seeing large beds of *Rangia* clams, finer sediments, and accompanying higher salinities. The habitats described by Parker (1960) formed the basis for the sedimentary facies defined by Fisher, *et al.* (1972) and reproduced on Figure 19. Note that narrow bay margin, river-influenced bay, enclosed bay with oyster reefs, and marsh facies are depicted. No data are given as to exact sediment composition, other than sand and mud at the margins, laminated mud near the river, and mottled mud in the bay centers.

Fig. 19. Environments and biological assemblages (Fisher, *et al.*, 1972).

LEGEND

- Prairie grasslands, mostly cultivated; mud and sand substrate; small mammals, fowl.
- Mixed pine and hardwood forests; sand and clay; mammals, fowl, snakes.
- Inland freshwater marsh; sand and mud; mammals, fowl.
- Swamp; sediment and water by overbanking fluvial systems; intermediate sized mammals, fowl, snakes.
- Fluvial woodland, water-tolerant hardwoods; mammals, fowl, snakes.
- Brackish to freshwater marsh; sand, muddy sand and mud, grades into saltmarsh; mammals, fowl, snakes.
- Saltwater marsh, frequently inundated by tides; sand, muddy sand to mud; mammals, fowl.
- Bay margin, shoal water bordering bay; sand to mud; mollusks.
- Pro-delta; mud and silt; sea worms, small mollusks.
- River influenced bay, low salinity; laminated mud, mottled mud; mollusks, crustaceans.
- Enclosed bay with scattered reefs; mottled mud; infaunal mollusks.
- Spoil; sand and silt; varying assemblages.
- Living oyster reefs; shelly bottom; epifaunal animals.



MAC BAYOU
N
LOST LAKE
LAKE CHARLOTTE
29°50'
OLD RIVER LAKE
LAKE ANAHUAC
COTTON LAKE
ANAHUAC
HOUSTON LIGHTING AND POWER DISCHARGE CANAL
29°45'
POINT BARROW
ANAHUAC CANAL
CEDAR POINT
DOUBLE
LONE OAK BAYOU
29°35'
STATUTE MILES
SMITH POINT
94°40'

DISCUSSION

There are many naturally occurring inhibitory or stress factors at work in gulf coastal estuaries. Some of these factors are strictly physical-chemical alterations of water, others relate to climate and physiography, while still others are strictly biological in nature. Knowledge of the range of extremes or effects that these environmental or ecological parameters have upon biological systems is imperative if one is to determine what effects man-made stress conditions might have upon these same systems. Artificial stresses are measurable only if sufficient knowledge of previous unstressed conditions is available. However, in the case of most gulf coast estuaries, good "baseline" data relating to the undisturbed state of the environment are not available. Trinity Bay is no exception to the rule that Texas bays lack sufficient data to establish a good baseline. As mentioned earlier, a number of excellent environmental studies have been carried out on Trinity Bay. Unfortunately, none of these studies were comprehensive enough to account for all possible variables, and the majority of them were confined to seasonal measurements at relatively few locations within the bay. Our sampling program certainly is no exception to this situation, except that we have made an attempt to get a broad, more comprehensive coverage of stations in both the bay and its environs. We also have endeavored to consider and measure those rarely measured variables which we consider important in controlling biological productivity. Apparently, such factors as total water and sediment bacterial populations, primary production, magnesium and calcium concentrations, total organic carbon, and abundances of meiofaunal organisms have never been examined in the Trinity Bay region. As our results have shown, these factors have shed new light as to the true nature of productivity in the Trinity estuary and permit us to suggest a better biological and hydrological management program for the Trinity River Basin and its estuary.

Physical-Chemical Factors Relating to Overall Water Quality

Temperature, salinity, and dissolved oxygen are considered parameters of wide natural variation and their extremes can exert a possible stress on purely marine and purely freshwater organisms. Copeland and Fruh (1970) stated that direct relationships usually can be ascertained between these three parameters and diversity indices. These factors are the most widely measured ones in marine ecology, although there is not much justification for their concentrated study. There is no question in the minds of most marine biologists that temperature plays an important role in the regulation of biological systems and that salinity is important to osmoregulation in estuarine organisms. Oxygen is necessary for the survival of all animals and in the respiration of plants, thus there is no doubt as to the importance that these three physical-chemical factors play in the survival of estuarine biota. In the marine end of normal estuarine ecosystems these three variables will vary seasonally, although the variations are not large enough to cause major disruptions in the function of an ecosystem. The same thing is true in the freshwater end of an estuary, except that salinity is no longer an important factor. It is in the midpoint of an estuary, half way between its mouth and end of tidal excursion, where the variation of these three factors must be known and considered. Here, animals adapted for salt water meet those that are more adapted for freshwater, and any major shift to either end of the salinity spectrum will cause changes in populations and animal diversity. For this reason, knowledge of the amount of runoff and discharge emanating from a river into its estuary becomes important.

Turbidity is another physical factor which can be related to natural stresses. Murky water is often thought of as a result of industrial pollution. Muddy water along the Gulf coast is, more often than not, a result of natural processes keeping fine detrital sediments in suspension. For this reason, natural turbidity patterns must be studied before blame for decreased radiant energy needed for photosynthesis is placed on human disturbances. The amount of material in suspension is also an important factor in the ingestion of food materials by filter feeding organisms.

Water temperature frequently has a greater effect on organisms in estuaries than the other parameters because it has a greater range over the year. Many mass mortalities have been recorded on the South Texas coast as a result of freezing temperatures (Parker, and Blanton, 1970), while extremely warm temperatures have apparently not been responsible for any known biological disasters on this coast. As suggested in Parker and Blanton (1970), temperature variations are so great on the Texas coast, and have been for so long, that most organisms are well adapted to temperature extremes. For this reason, temperature pollution as it affects estuarine organisms is probably negligible in Texas bays.

Salinity

It has been stated many times that the inflow of freshwater to the estuary is necessary to maintain the reduced salinities necessary for various life stages of the marine organisms. Too much freshwater can be lethal to the majority of truly marine animals and too little can be limiting to such low salinity animals as *Rangia* clams and river shrimp. A salinity gradient is the prime requirement of estuarine organisms in that both the adults and various stages of juveniles must seek their optimum but varying salinity requirements. Baldauf, *et al.* (1970) found that a direct correlation existed between the amount of freshwater occurring in the marshes above the Trinity River delta and the areal distribution of shrimp and blue crabs. They found that few of these crustaceans could be taken in areas when large amounts of freshwater flooded the marshes, while they were far more abundant in these same habitats when the amounts of freshwater were reduced.

The general effects of river discharge and runoff on estuarine life can be observed at all levels of salinity on the Texas coast. Estuaries on the Louisiana-Texas border are nearly fresh to their Gulf entrances, and they are more characteristic of a freshwater lake (Sabine Lake) than of a marine bay. Even so, the magnitude of renewable resources harvested from this nearly freshwater system is no smaller than those harvested from the more saline bays to the south. Shrimp, blue crabs, and estuarine and marine fish are abundant in Sabine Lake and have remain so for as long as records have been kept (Parker, and Blanton, 1970). The same is true for the same fishery resources in the intermediate salinity bays of the central Texas coast; such as, Matagorda, Lavaca, and San Antonio Bays.

Here, salinities range half way between wholly marine and nearly freshwater for long periods and tend to be typical of the mixed or mesophytic estuary. Fishery production has not been significantly affected by slow salinity changes, but more so by sudden catastrophes; such as hurricanes or disease.

The bays of the coastal bend have the greatest variation in salinity and can often remain at true marine levels or even in a hypersaline state for a number of years (Parker, 1955). On the other hand, these same bays may experience, from hurricanes, extreme flooding and may be inundated by freshwater for long periods of time (Berry, 1969). Salinity changes in this region appear to be more critical to the survival of aquatic organisms than in other portions of the Texas coast, perhaps because of the more marine nature of the biota to begin with. These organisms are more adapted to higher salinities in this semiarid zone, thus occasional floods wreak greater havoc on the populations. The Laguna Madre, a coastal lagoon with little or no freshwater runoff, has perhaps the highest level of production in the world (Parker, and Blanton, 1970). These observations, relating to the amount of freshwater needed to sustain large commercial fisheries, tend to support a premise that regulation of freshwater flow into an estuary apparently has not had much long-term effect in the past and may not have much effect in the future on the total biological productivity of most Texas bays.

Dissolved Oxygen and pH

The concentrations of dissolved oxygen (DO) in the Trinity River estuary is considered to be at a "healthy" level by Espey, *et al.* (1971), who summarized seven years of observations as a trend towards a constant gradual increase in DO in recent years. Gloyna and Malina (1964) stated that observed DO values "indicate high productivity"--probably meant as capable of supporting considerable aquatic life. The aforementioned authors observed that there was also a diurnal DO fluctuation of sufficient magnitude to support biological activity. Furthermore, the diurnal pH fluctuation correlated directly with the dissolved oxygen fluctuations. The pH/DO pulse is significant in that during the hours of darkness, respiration contributes enough CO_2 to change the pH, while during daylight hours, oxygen values vary directly with plant production. If these two parameters show consistent and steady daily fluctuation, it is likely that the ecosystem has struck a natural balance between oxidation and respiration, centering around a healthy production of organic matter.

Our own survey was entirely inadequate for the determination of the diurnal fluctuations of parameters which control phytoplankton productivity, since 24 hour stations occupied in several localities, from up river to the mouth of the bay, should be monitored. A survey of this sort should surely be carried out in the near future; in order to establish whether or not a normal ecosystem respiration is characteristic of this bay. The fact that the pH values measured throughout our single areal coverage of the bay were relatively consistent within the areas of permanent freshwater, marine derived waters, and industrial waters, suggests that the bay "respires" normally.

Metallic Ions

Several metallic ions were examined as to their distribution throughout the Trinity Bay region. All were determined through precision analytical techniques. Most of the analyses were relatively uniform and well within the limits of most estuarine ecosystems. For instance, the Mg/Ca ratios show more or less typical values for freshwater, intermediate values for much of the bay, and the higher values more typical of marine waters at the mouth of the bay. As shown on Figure 10, there does not appear to be an ecosystem disturbance factor which could be related to the presence or absence of magnesium and calcium. The two poisonous metallic ions, mercury and arsenic, were surveyed for the bay region and of the two, only mercury seems to be in excess in any part of the system. Arsenic was uniform and low throughout the bay and it poses no threat to the well being of organisms living in the bay or humans who might eat those organisms. High values of mercury (Fig. 9) were found in the southwest corner of Trinity Bay, which would suggest derivation from the Houston Ship Channel. Although an order of magnitude higher than "acceptable levels", the mercury concentrations in the ship channel water probably have little effect upon the overall ecosystem, and are probably not concentrated in food organisms to levels dangerous to humans.

Waves and Sediment Transport

Wave action, which is considerable in this bay, because of its relatively long fetch in the direction of the prevailing winds, tend to not only keep fine sediments in suspension in the upper portion of the bay, but tend to cause thorough mixing throughout the water column. The upper bay is relatively shallow thus sediments are almost continually in suspension, inhibiting the growth of the filter-feeding oysters. Sediments are being eroded from the western portion of the Trinity River delta, and they are prograding in the area where the present active river mouth is located near Anahuac. Rates of transport of sediments by river discharge are greatest in the upper estuary, just above the channel floor, while transport over shoals by density currents is strengthened by wave agitation and tidal turbulence. Deposition takes place where tidal flow is diminished, but major shoals are not developed because these sediments are actively recirculated by moderate tidal turbulence, waves, and adjective density mixing (Nichols, and Poor, 1967). No amount of up-river control will effect the overall wave action, tidal flow, and wind-driven circulation, which are the primary agents for deposition and cause the major turbidity from sediment suspension.

There is, of course, a major possibility that the reduction of flow may reduce the source of sedimentation in Trinity Bay. However, this bay is one of the few that have deepened significantly in the past 100 years (Shepard, 1953). These data suggest that the amounts of sediment being deposited through Trinity River runoff is insufficient to keep up with scour from wind, waves, and tides. For all intents and purposes, the coarser sediments of the Trinity River are already impounded in upper drainage basin reservoirs and the fine material remaining in suspension is not likely to be trapped at Lake Livingston. The rather remarkable fact derived from Shepard's (1953) study was that 1.15 feet of deepening took place between 1854 and 1933, long before any impoundments existed on Trinity River. Apparently the Trinity flow has virtually no effect upon

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ENVIRONMENTAL ASSESSMENT OF THE TRINITY RIVER DISCHARGE ON PROD--ETC(U)
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the general circulation and general nutrient supply to the Bay. There was probably little erosion of soils in the Trinity Basin prior to the early 1930's, since dense forests and prairie grasses held in the soil. Some immediate investigation is needed as to depth changes and shore changes along the north shore and in the delta during the past 25 years. Data for these changes should be available in surveys carried out by the U.S. Geological Survey, from the U.S. Coast and Geodetic Survey smooth sheets, and from the U.S. Corps of Engineers. What is more important is the need to establish 1) whether the present flow of the Trinity is providing enough hydraulic head to maintain a *status quo*, 2) will any reduction of the flow bring about further erosion along the shores in the future, and 3) is *subsidence* responsible for bay deepening.

These natural parameters of stress are relatively immune to the activities of man. Water temperatures may be modified by man, but normally only at the local level--in the vicinity of a coolant water discharge canal. On the other hand, it is possible to modify a salinity gradient in a narrow estuary through intensive restrictions of freshwater discharge. Freshwater inflow cannot be stopped entirely however, as there is always local runoff and groundwater flow. It is almost impossible to artifically increase dissolved oxygen levels beyond normal concentrations. On the other hand, it is common for man to reduce oxygen levels through his own activities, chiefly by discharging large amounts of oxidizable organic matter into areas of limited circulation. Large amounts of dissolved oxygen can be consumed through high BOD's, leading to poor water quality These conditions can develop in restricted estuaries; such as, the Houston Ship Channel or Clear Lake (near La Porte, Texas). It is extremely unlikely that toxic oxygen levels can be induced in large open bays, with their great surface areas available for transfer of oxygen between air and water.

Increased turbidity can be brought about through industrial pollution, but in Trinity Bay industrial turbidity is greatly overshadowed by turbidity produced by the stirring of fine bottom sediments by winds and waves. Man cannot yet change the direction or intensity of winds, nor can he control most of the stress-causing physical-chemical factors in a large open bay system. However, it is possible that a bay can be flushed completely by massive flooding in the coastal portion of a drainage basin (Parker, and Baker, 1969); or it can be tremendously modified by the periodic hurricanes which strike the Texas coast. These are nature's pollution efforts and the forces involved could never be equaled by man. It is interesting to note that, even with the devastating damage wrought by floods and hurricanes, estuarine conditions return to normal in a year or less. Even environmental damage brought about by man is repaired much more rapidly than imagined by most environmentalists (Parker, and Blanton, 1970).

Factors Controlling Productivity in Trinity Bay

In order to determine and define the health of a bay, one has to select one or more indices of biological or chemical activity and monitor these indices for a long enough period to establish correlations between nutrient sources and biological productivity. For the purposes of this short-term study, the indicators upon which most emphasis is to be placed are nutrients, primary productivity (phytoplankton and bacterial production), and selected water quality parameters. A prescription for the healing of an "unhealthy" bay has been given by Odum and Wilson (1962), who suggested that it would be necessary to: 1) reduce turbidity, 2) promote and retain grassy bottoms, 3) insure proper normal circulation, 4) maintain some areas of shallow water (high energy environments) by restricting dredging or deepening, and 5) prevent the complete flushing of the bay by floods. While this prescription is an oversimplification of a cure, and beyond the efforts of man to impose such measures upon large bays, there is considerable validity to these suggestions for bay improvements. Although all elements mentioned previously relate to major physical processes, bay health also may be improved through judicious management of nutrients, growth substances, and other elements which promote overall biological productivity.

Perhaps the most important set of controls governing productivity is the availability of nutrients. It is on this point that much controversy has hinged. Statements have been made over the past few years that impoundments on Texas rivers have in the past and will in the future withhold nutrients from the bays. Catastrophic losses in fisheries resources will be sustained through the loss of phytoplankton which need these nutrients to survive and grow. Let us examine this problem in the light of previous studies and from new data produced through this present investigation.

The most important nutrients in an estuarine ecosystem are nitrates, nitrites, and phosphates. Other substances needed to sustain biological production are organic carbon sources, vitamin B_{12} complexes, and metallic ions (chelating agents) which are needed for the formation of chlorophylls and pigments. The Trinity River may be the most important source of nutrients for Trinity Bay, but large amounts are derived also from direct runoff from adjacent land, the Houston Ship Channel (via Cedar Bayou and the HL&P canal), and by tidal exchanges between other parts of the Galveston Bay system and the mouth of Trinity Bay. Nitrogen compounds are considered, by a number of investigators, to be the most limiting of nutrients. A limiting element is one in which its presence alone allows growth of an organism, but when the concentration of this element decreases below a certain minimum, growth or development ceases. Lake Livingston is considered to be already low in nitrogen (Fruh, and Masch, 1972), a fact of some significance when one considers that it is the closest major impoundment to the mouth of the Trinity River. In addition, Redfield, Ketchum, and Richards (1963) believe that all inshore waters are likely to be low in nitrogen and could be depleted of all nitrogen before phosphorus would be exhausted from the same water by biological uptake. It was mentioned earlier that a 10:1 ratio of nitrogen to phosphorus is best for phytoplankton growth. Copeland and Fruh (1970) in their study of Galveston Bay ecosystems found phosphorus concentrations to be high and nitrogen low, thus ionic concentrations are reversed from the ideal proposed ratio. Data from our own survey reinforced Copeland and Fruh's observations, in that at every station we found 10 times more orthophosphate than nitrates plus nitrites, an even greater reversal of the ideal conditions of 10:1 nitrogen to phosphorus. The tenfold differences are so great that it is possible the amounts of nitrogen and phosphorus in all chemical states might exist in a different ratio than we or Copeland and Fruh (1970) established for Trinity Bay.

Carpenter, Pritchard, and Whaley (1969), in a controlled study of the factors governing primary productivity, found that at a rate of consumption of nutrients of 4 mg atoms/l of nitrogen and 0.5 mg atoms/l of phosphorus per day, all nutrients would be consumed in a given volume of water in one to four days. However, in the open ocean, this rate of uptake did not occur and the authors believed that there must be rapid regeneration of phosphorus and nitrogen in the upper levels of the open ocean where the tests were made. They also suggested that grazing by zooplankton is the principal mechanism that maintains nitrogen and phosphorus levels needed to sustain the phytoplankton base.

The utilization rate of these nutrients within the food chain may furnish an explanation for high concentrations of phosphorus in Trinity Bay. Redfield, *et al.* (1963) give the ratios of utilization of carbon, nitrogen, and phosphorus in biological systems as 106:26:1 respectively. It is of considerable significance that nitrogen is used up in phytoplankton nutrition 26 times faster than phosphorus, and carbon is utilized 106 times faster than the other nutrient substances. Nitrogen is recycled rapidly because it has no reservoir in the sea, since all nitrogenous compounds are soluble (Brooks and Kaplan, 1972). These authors also state that the cycling of phosphorus depends upon the absorption into and the release of this element from solution. Since phosphorus is recycled slowly, there will always be an abundance of it in solution, especially when its solution is aided by carbon dioxide (CO_2) produced by respiration (Fuller, 1972).

Respiration (the production of CO_2 and consumption of O_2) is as important in the maintenance of biological productivity in Trinity Bay as is the photosynthetic process. The ratio of photosynthesis (P) over respiration (R) or P/R is used as an indicator of the autotrophic (manufacturing its own food) or heterotrophic (eating other organisms for food) nature of an aquatic community base. Copeland, Odum, and Cooper (1972) state that when the P/R is greater than one the community metabolism is most likely autotrophic--plants are abundant enough to support the entire food chain. On the other hand, when the P/R is less than one, the metabolism is likely to be heterotrophic--the primary consumers, or second level of the food chain, graze on river-borne organic matter and detritus in the bay because the phytoplankton cannot furnish enough energy to support the entire community.

Studies by Copeland, *et al.* (1972) and Gloyna and Malina (1964) demonstrate that under normal conditions Trinity Bay metabolism is heterotrophic (P/R less than 1). High turbidity reduces sunlight and the level of photosynthesis, while river-borne nutrients and organic matter allow a higher level of secondary productivity. This premise is augmented by our own observations of bacterial populations, which indicated that extremely high numbers of heterotrophic bacteria characterize the waters and sediments of Trinity Bay, furnishing a solid food base for secondary consumers. Copeland, *et al.* (1972) even managed to quantify the heterotrophic nature of Trinity Bay by stating that the upper bay community was between 43-72% dependent upon river-borne organic matter to support the extremely high secondary productivity. Odum (1963) as quoted by Hooper (1969) states that the imbalance between productivity and consumption is characteristic of a high level of enrichment, or a high loading of organic matter on to the system. There is some question in our minds, however, as to the source of the organic matter which enriches this particular ecosystem. At the time our measurements of nutrients and productivity were made, neither nutrients nor total organic carbon were high in the river. What was even more puzzling was the relatively low level of production in the freshwater and the slightly brackish marshes in the lower reaches of the river estuary. If the source of organic matter is not the river nor the delta marshes, where does the heterotrophic nature of this bay originate?

A source of carbon and nutrients, which has not been considered before, is the tremendous populations of estuarine organisms that are spawned in the open Gulf and migrate in huge numbers up into the upper estuaries. Many of them are eaten or die there, contributing to the mass of organic matter through their own and their predators' eventual decay. The extraordinary populations of bacteria living in Trinity Bay may exist there because of the large amounts of organic matter furnishing a carbon source for their growth and reproduction. Both the bacteria and the degraded organic matter are ingested by the extremely high populations of infaunal invertebrates (Table I), which in turn furnish an excellent food base for larger members of the food chain. These animals in turn may either die, return to the Gulf, or remain living in the estuary. In any event, there seems to be a very efficient recycling of organic matter which is independent of food sources from either the river or from the surrounding marshes.

Another explanation of methods of fueling a heterotrophic ecosystem is that the Houston Ship Channel and other industrial waterways which empty into Galveston Bay furnish high carbon sources which eventually find their ways to Trinity Bay through tidal circulation. It is well known that the amount of organic matter or high carbon waste is extremely high in the Houston Ship Channel. Large amounts of organic matter are added to this system from Clear Lake, Texas City, Galveston, and the high population centers between Baytown and Trinity Bay. Once the tidal waters have perhaps "cleansed" some of this industrial and domestic waste, these rich carbon sources can be degraded into refractory (food-type) carbon by the large bacterial populations in Trinity Bay. A glance at most of the figures relating to the distribution of the various ecological factors measured in our own study demonstrate that there is considerable movement of water from the direction of the Houston Ship Channel into the south-western portion of the bay.

The important fact relating to biological production is that the total productivity within Trinity Bay is relatively high, whether it is autotrophic or heterotrophic. Light and dark bottle productivity measurements were carried out by us, but indicated little phytoplankton production taking place either in the open bay or in the marsh waters. One thing was evident, however, and that was the fact that respiration apparently exceeded oxygen production over both 12 and 24 hour period measurements. The mean annual productivity of the open ocean surface is 0.37 gm/m^2/day (Vishniac, 1968) and 0.74/gm/m^2/day in continental shelf waters (McConnaughey, 1970). Ryther (1959) gives the total production of the exceedingly rich turtle grass flats as 20.5 gms/m^2/day (two orders of magnitude higher than the ocean). On the other hand, Gloyna and Malina (1964) found that the photosynthesis rate in grass flats in Galveston Bay ranged between 4-34 gms/m^2/day, considerably higher than the other quoted values. Much higher values have been recorded, for a similar habitat, from the Laguna Madre in Texas (Thomas and Simmons, 1960: Parker, 1959), but the waters are much clearer and warmer than those of Galveston Bay. Even so, primary production of plants in most bays and estuaries is higher than in most shelf and open ocean waters, in spite of the high turbidity and greater sources of pollution.

Copeland and Fruh (1970) state that there are more nutrients present in Galveston Bay than are being utilized by the relatively low phytoplankton populations. Apparently greater phytoplankton production is in some way being inhibited. Possible inhibiting factors could include an excess of chelating agents that remove necessary trace metals needed for protein synthesis, reduced light penetration from high natural turbidity, the presence of toxic chemicals, or the presence of large amounts of biological waste materials (ectocrines) resulting from high biological metabolism.

Productivity as a Function of Hydrology in Trinity Bay

It is not possible to determine the amounts of river discharge needed to sustain high biological production in Trinity and Galveston Bays until the relationships between circulation, nutrient levels, and river discharge are well understood. If indeed Trinity Bay is supplied with the limiting nutrients for aquatic life by the Trinity River alone, the importance of controlling the amount of water which reaches the bay cannot be underestimated. However, as we have demonstrated earlier, there is some question as to whether or not the river does supply all nutrients for bay production, or even if the bay's production is phytoplankton-based. There is also the possibility that the present nutrient supply of the bay, which appears to be recycled through a bacterial-deposit feeding food chain, might be removed from the bay through increased harvest of seafood. In the likelihood of this event taking place, a freshwater supply must be maintained. In addition, the mixing processes and pathways of water and nutrient transport must be considered along with the discharge available. As mentioned previously, one major benefit from a high river discharge is the maintenance of a salinity gradient in the estuary. There is no doubt in our minds that many marine and estuarine organisms need a continuing source of freshwater and the resultant lowered salinities in some phase of their live history, although it may be more of a need for protection from predators that cannot withstand low salinities than a strictly physiological limitation. A typical salinity gradient characterizes the present Trinity estuary (Fig. 6). This gradient fluctuates considerably, from a rapid change from fresh to gulf salinity during drought years to a gradual change during periods of high rainfall and runoff. This relationship is more obvious in the graphs of salinity versus river discharge for six stations in Trinity Bay as shown on Figures 20 and 21. These data were collected through the Galveston Bay Project (Huston, 1971), and the U.S. Geological Survey (1969, 1970, and 1971). The graphs demonstrate dramatically that salinities in Trinity Bay are inversely proportional to the discharge of the Trinity River. This observation is further supported by the works of Pullen, *et al.* (1971) and Renfro (1960).

As we have mentioned before, the flow of the Trinity River may or may not control the amount of nutrients entering Trinity Bay. Some of the nutrients may enter the bay through direct runoff from the adjacent land,

and some may be derived from the smaller streams surrounding the bay; such as, Cross Bayou, Double Bayou, and Lone Oak Bayou. Opinions differ widely concerning nutrient concentrations which occur in the river. Baldauf, *et al.* (1970) observed that phosphorus levels were highest in the river during low river flow and Dupuy, *et al.* (1970) found that both nitrates and phosphates were highest during low flows past the Romayor gauging station. Trent, *et al.* (1967) could find no correlation between the seasonal concentration of nutrients and the flow of the Trinity River, while Pullen, *et al.* (1971) recorded the highest levels of dissolved organic nitrogen during periods of highest river flow. These same authors, however, did not find a sustained correlation between phosphate levels and river flow.

These conflicts in the literature concerning the correlation between nutrient concentrations and river flow are largely the result of sampling at different seasons and in different years. Many factors determine the amounts of nutrients in the river, including the rate and time of crop fertilization on land, amounts of precipitation, and the presence of additional sewage treatment facilities. When precipitation is high in the drainage basin, more nutrients can be washed into the river; but as the flow becomes greater, the dilution factor also becomes larger and the total concentration of nutrients per unit of measure may not increase. However, as the estuary is a "nutrient trap" (Copeland and Fruh, 1970), the total effects of the nutrients being washed into the river will ultimately be felt in the bay. This "ultimate effect" process is confirmed by Pullen, *et al.* (1971) who observed that the highest phosphate levels in Trinity Bay followed periods of high river flow. Figure 22 is a summary

Fig. 20. Comparison between river discharge and bay salinity at three nearshore Tracor stations, 1968-1970, Trinity Bay region, Texas.

MEAN MONTHLY DISCHARGE *VS* BAY SALINITY

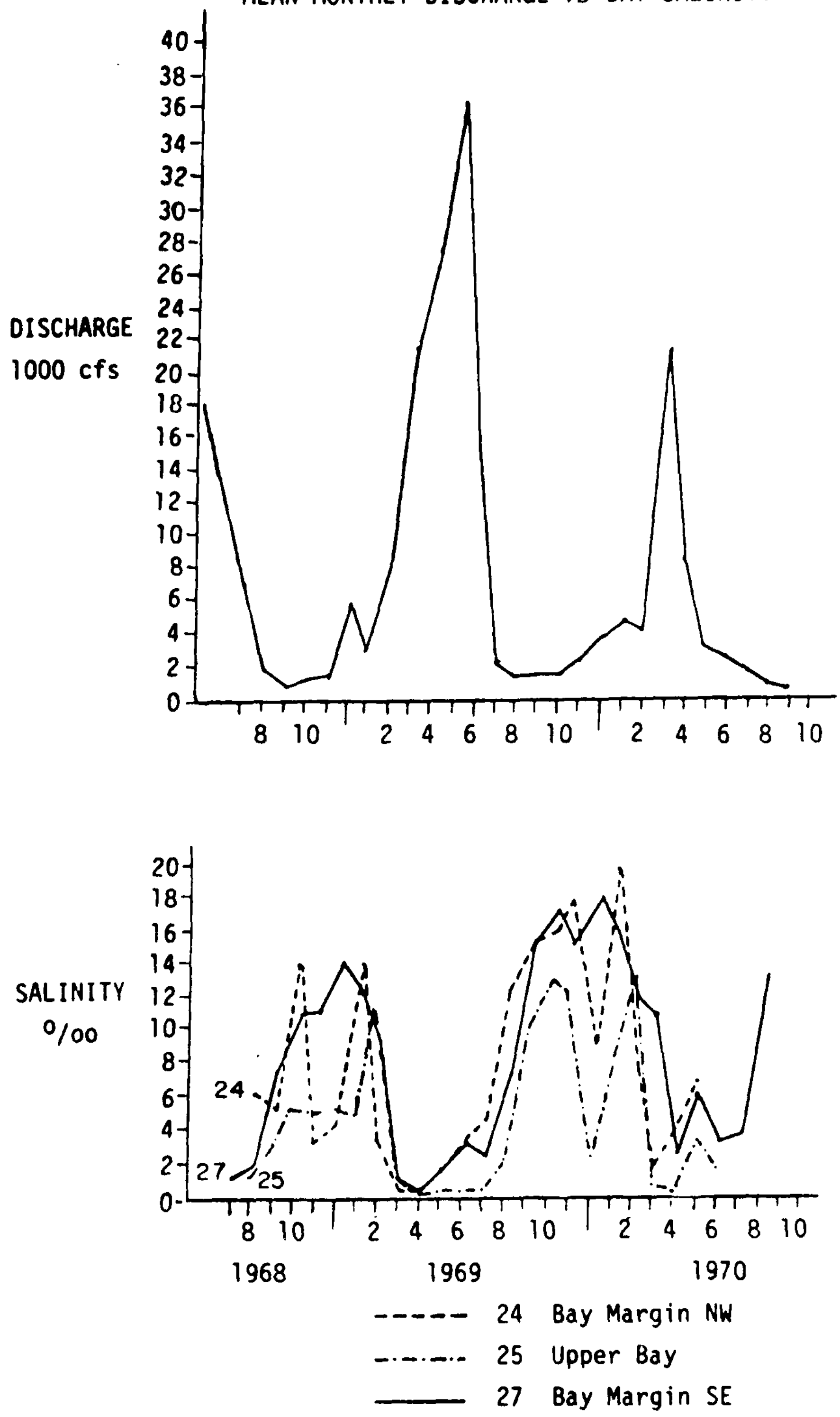
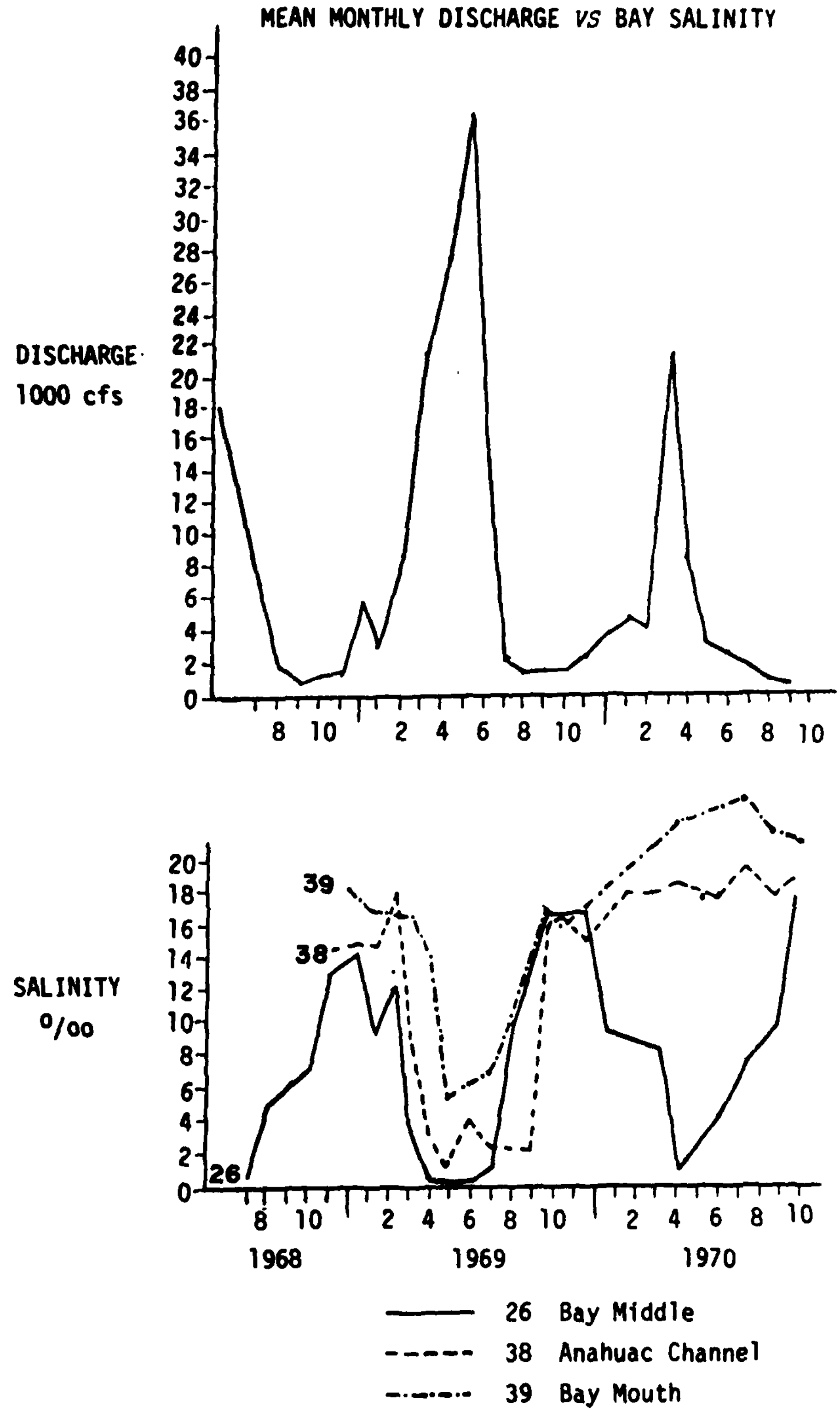


Fig. 21. Comparison between river discharge and bay salinity at three bay center Tracor stations, 1968-1970, Trinity Bay region, Texas.

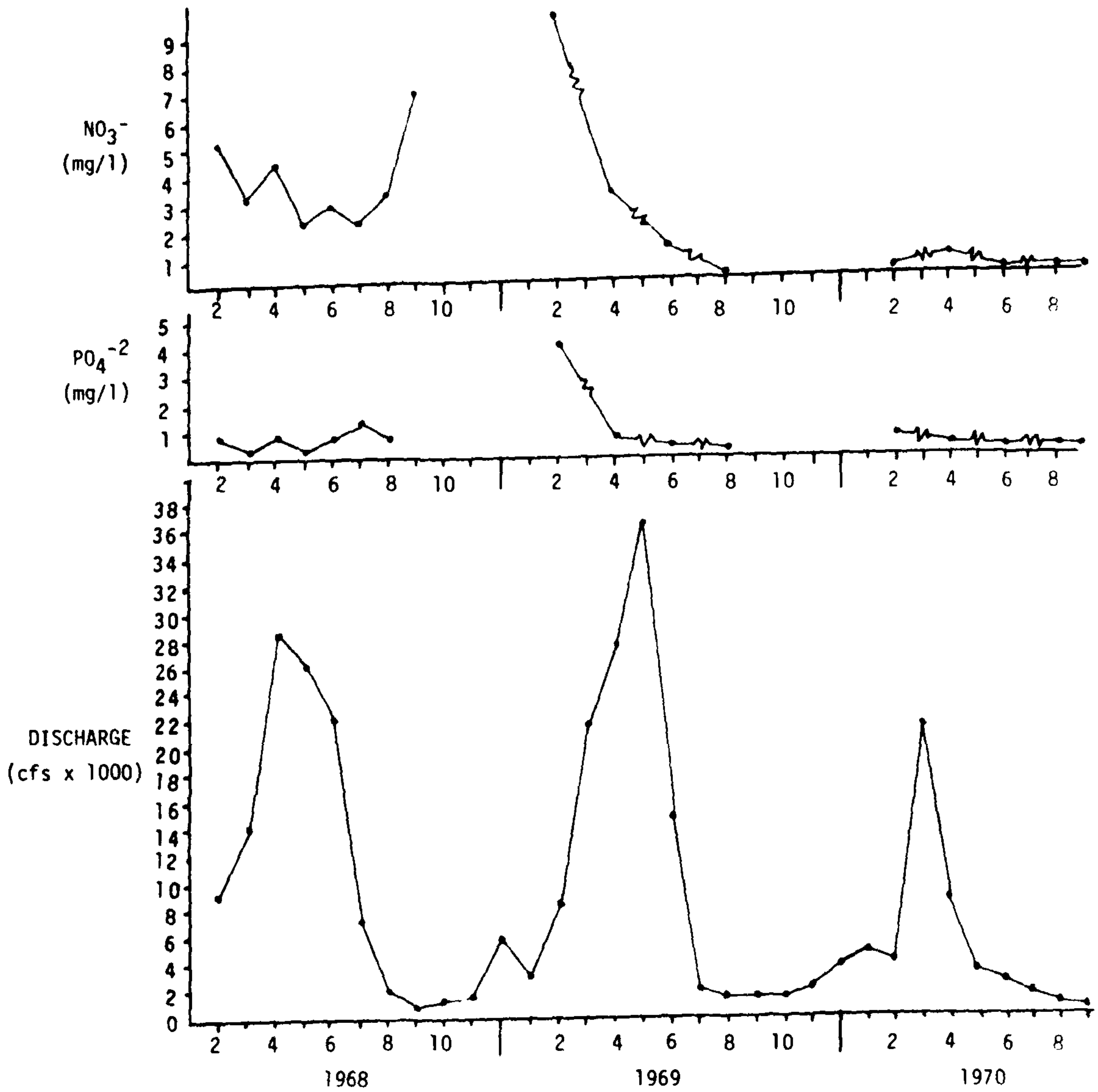


MEAN MONTHLY DISCHARGE VS BAY SALINITY
DISCHARGE
1000 cfs
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
8 10 2 4 6 8 10 2 4 6 8 10
SALINITY
o/oo
20
18
16
14
12
10
8
6
4
2
0
39
38
26
8 10 2 4 6 8 10 2 4 6 8 10
1968
1969
1970
26 Bay Middle
38 Anahuac Channel
39 Bay Mouth

Fig. 22. Comparison between river discharge and nutrient concentrations in Trinity Bay, Texas.

TRINITY RIVER MEAN MONTHLY DISCHARGE

AND CONCENTRATIONS OF NUTRIENTS

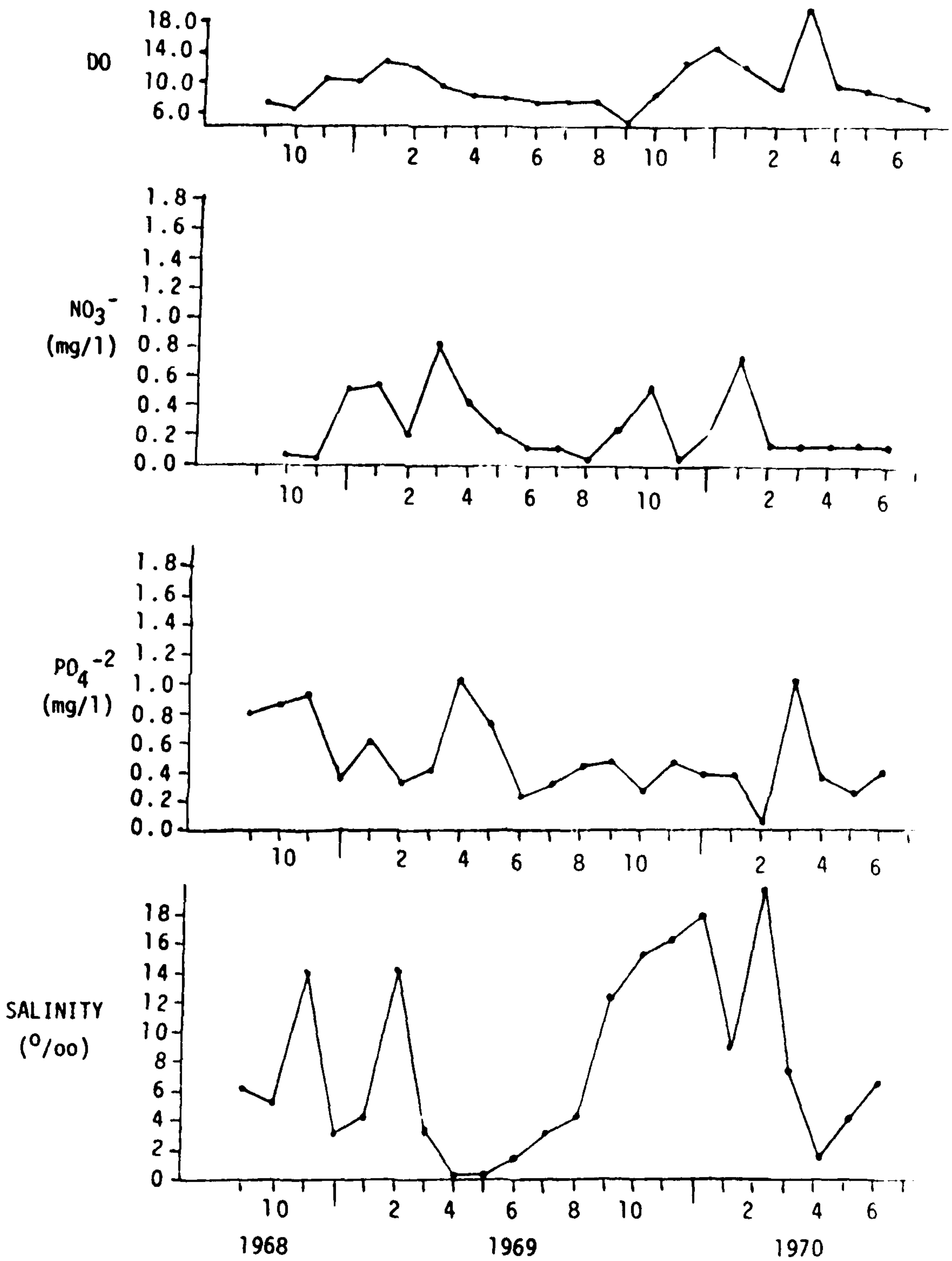


of three years of river discharge and nutrient level data taken by the U.S. Geological Survey (1969, 1970, and 1971). These data for nutrients are not complete enough to allow one to make close comparisons between water flow and nutrient levels. There is a suggestion that high nutrients were occasionally associated with high river discharge prior to the middle of 1969 when nitrate levels were generally over 2 mg/l regardless of discharge. However, it is also evident from these graphs (Fig. 22) that there was a striking drop in nutrient levels after June, 1969. Not even the major discharges in March and April of 1970 raised the level of nutrients to those prior to the middle of 1969. According to our own data, these low levels of both nitrates and phosphates still characterize the lower river estuary and Trinity Bay.

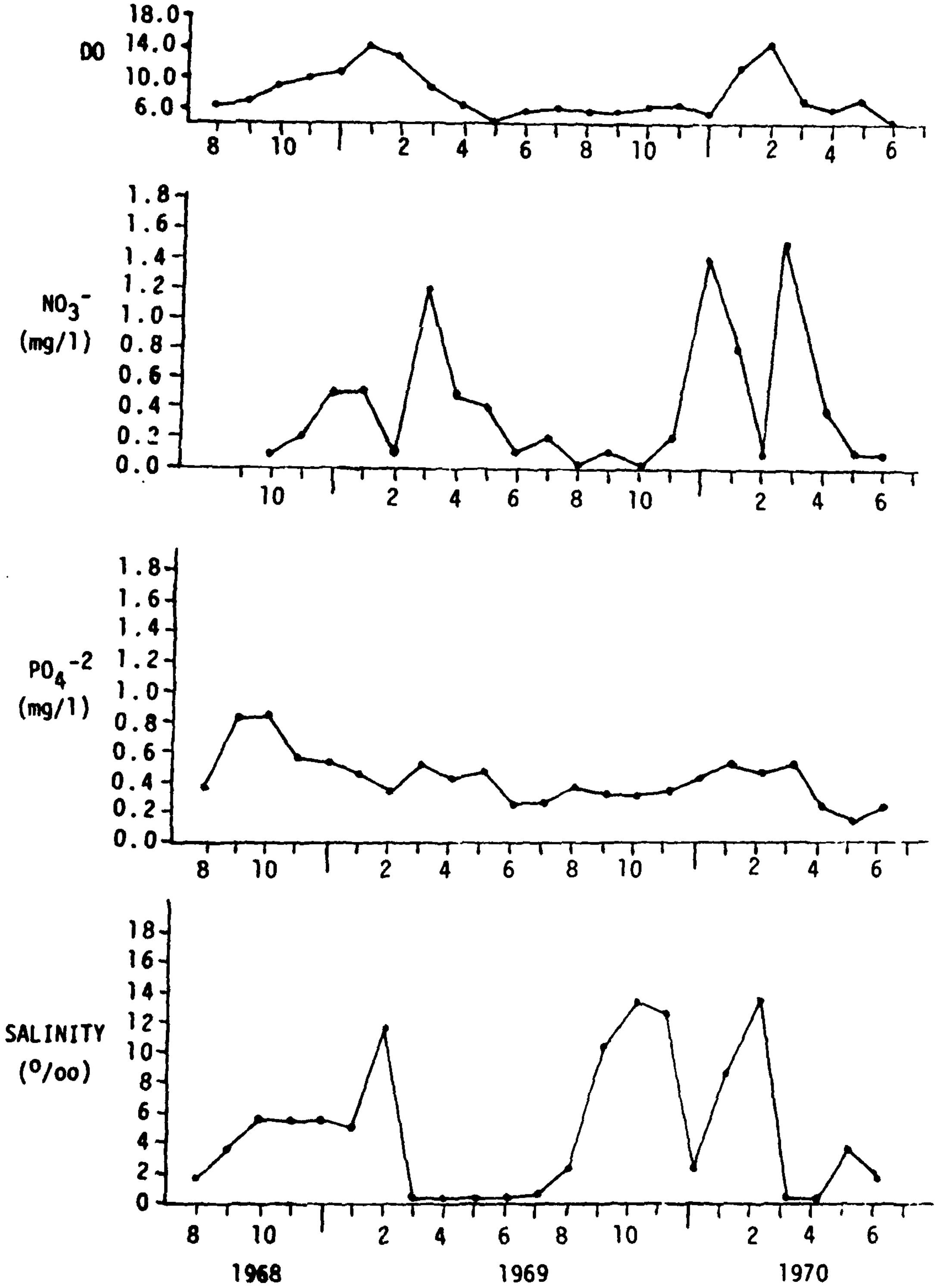
Espey, *et al.*(1971) state that phosphorus levels in the bay had been increasing over the six year period between 1964 and 1970. Hastings and Irelan (1947) found even higher levels prior to 1964, citing a mean value for nitrate in the Trinity River for water year 1946 as 2.99 mg/l, nearly 10 times that of recent years. The U.S. Geological Survey (1968) cited a mean value of 6.8 mg/l for nitrates during the water year 1968, three times higher than in 1946. However, the mean annual flow rates of the Trinity River in both 1947 and 1968 were almost identical--11,590 cfs and 11,520 cfs respectively. Although there may have been a major increase in phosphates and nitrates between 1946 and 1969, it is more apparent to us that there has been a sudden dramatic decrease during the past two and one-half years. Two explanations for this drop in nutrients are possible: 1) it was towards the middle of 1969 that phosphates were generally removed from detergents and that some attempt was being made to reduce overfertilization and eutrophication in estuaries; and 2) Lake Livingston became an effective impoundment of Trinity River water. The latter explanation does not account for the fact that mean river discharge has not changed significantly (Fig. 22) and that while floods still occur (March, 1970) the levels of nutrients in solution do not respond to the increase in water.

Additional data for nutrients, dissolved oxygen, and salinity at the six regular Galveston Bay Project stations, derived from Huston (1971), are graphed for 24 consecutive months on Figures 23 through 28. The Galveston Bay Project stations are unique in that most of them have been occupied continuously through at least two annual cycles. Data for other physical parameters (but not nutrients) were taken at another 15 stations in Trinity Bay, from 1963 through 1972, although not reproduced here (Travis, 1972). All data given in Figures 23 through 28 were determined from water samples collected at mid-depths and representative of the whole water column in this well-mixed bay. Three of the Galveston Bay Project stations are located close to shore (Stations 24, 25, and 27) and three are located in deeper water some distance offshore (Stations 26, 38, and 39). Their locations are shown on Figure 2. Some similarities in all four parameters throughout the two years can be found at stations 24, 25, 26, and 27. Three of these stations are located close to shore, thus similarities might be expected. Station 26 is in the middle of the bay but may be part of the same water mass found at stations 24 and 25. Maximum values for dissolved oxygen all fell between December and February of both years, which is to be expected as oxygen saturation is greatest in coldest waters. Likewise, the minimum values for all stations occurred in

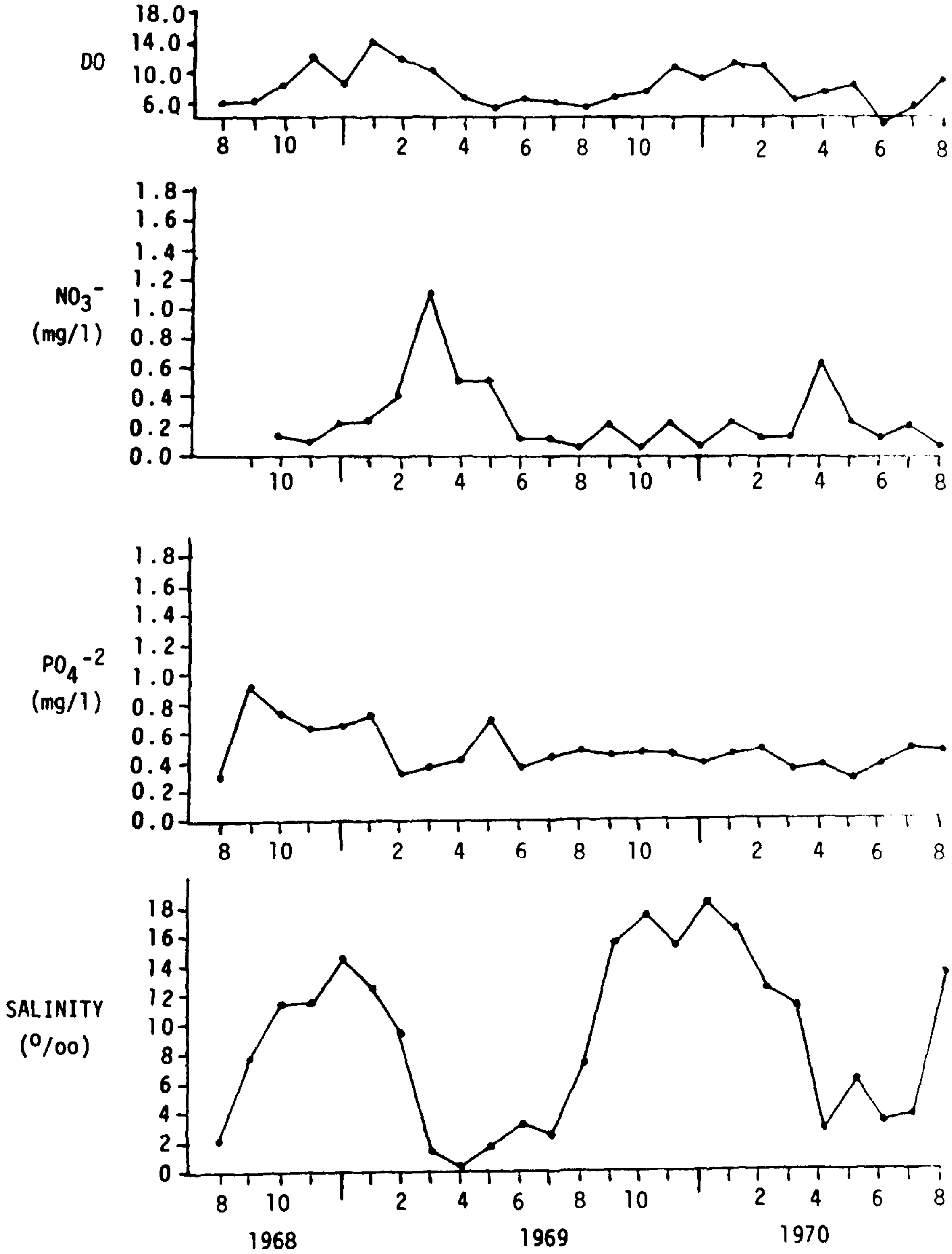
Figs. 23 through 28. Comparisons between salinity, nutrients, and dissolved oxygen at six Trinity Bay Tracor stations.



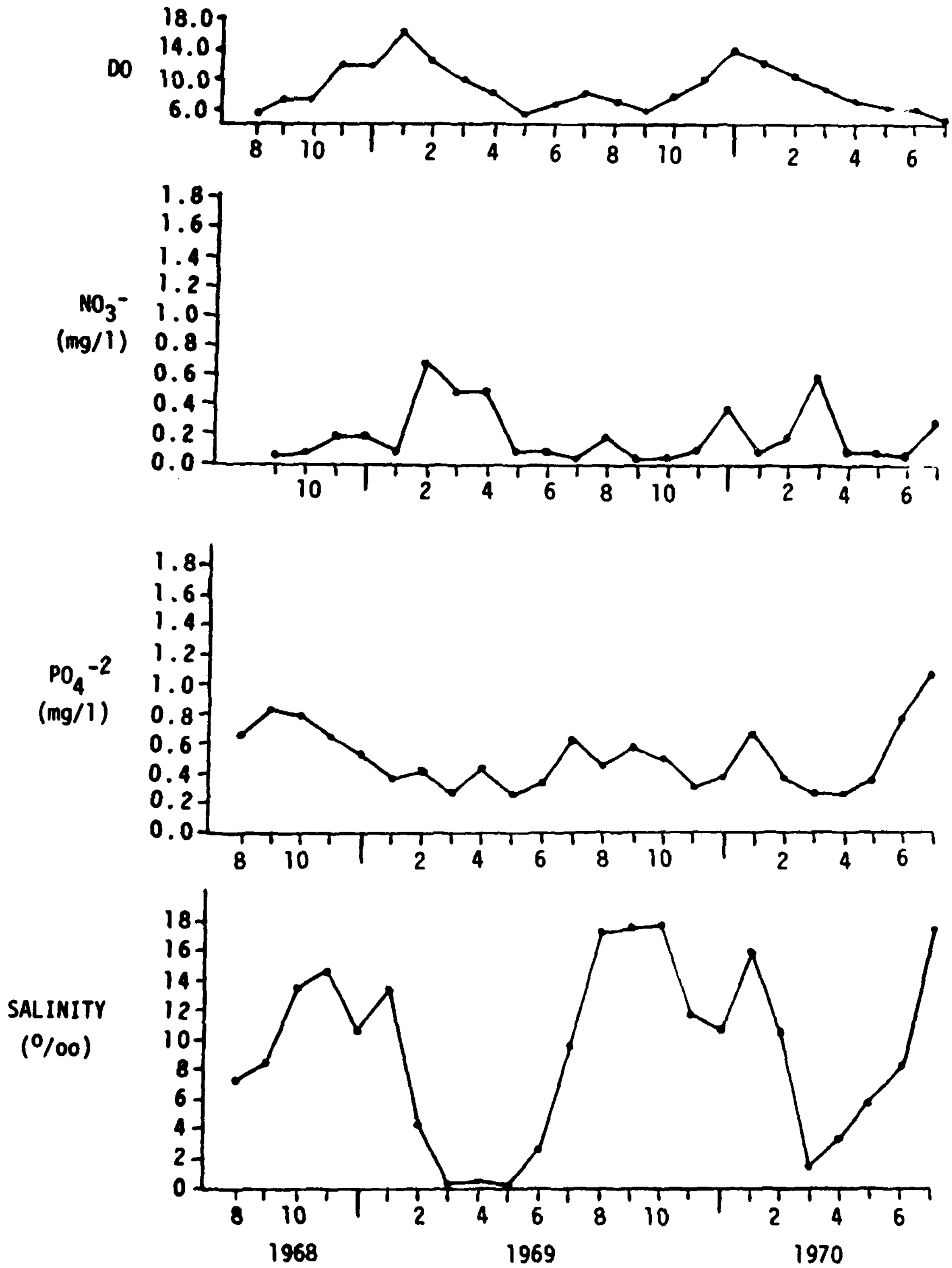
GALVESTON BAY PROJECT STATION NUMBER 24



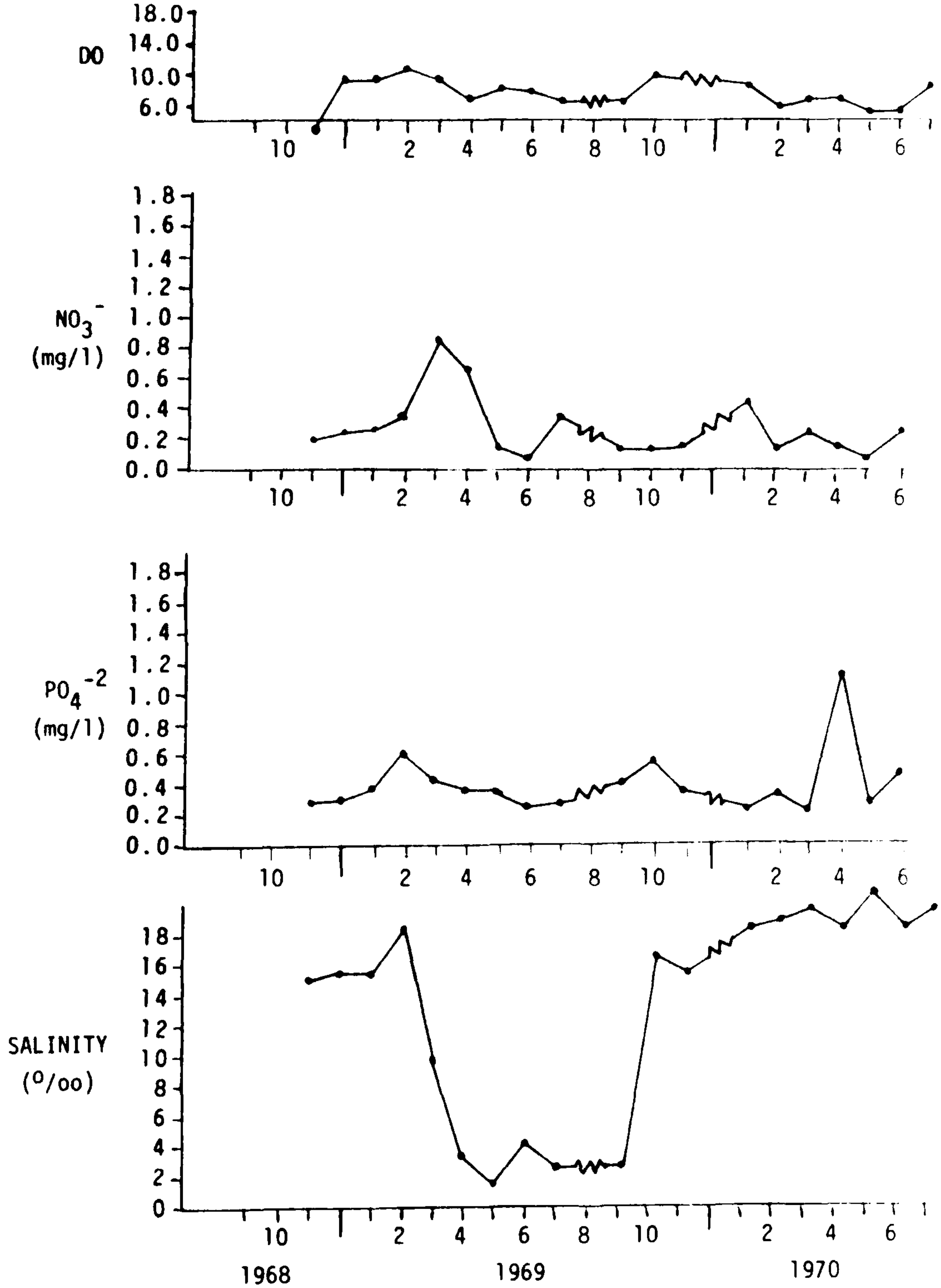
GALVESTON BAY PROJECT STATION NUMBER 25



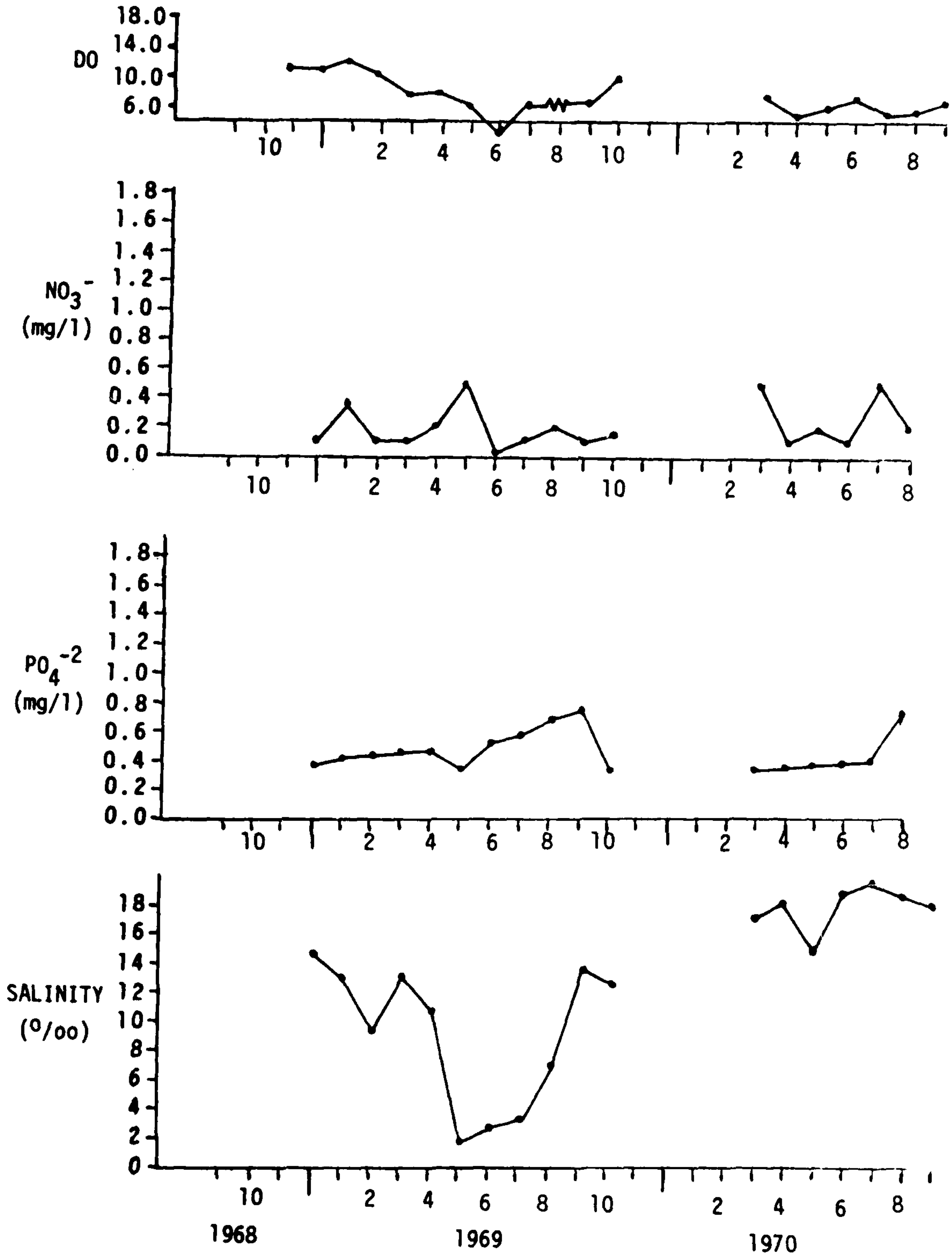
GALVESTON BAY PROJECT STATION NUMBER 27



GALVESTON BAY PROJECT STATION NUMBER 26



GALVESTON BAY PROJECT STATION NUMBER 38



GALVESTON BAY PROJECT STATION NUMBER 39

the late spring of each year, a normal situation following spring plankton blooms and the simultaneous warming of the waters. In general, the highest nitrate values appeared at the same time that salinities dropped drastically, indicating high runoff and accompanying high nitrate influx. A good correlation can be observed between salinity and phosphate concentrations, although ratios are reversed from those of nitrates. High salinities correlate closely with high phosphates at stations 25, 26, and 27, and to a lesser degree at station 24. There is a greater fluctuation of phosphate values at station 24 because it is closest to the center of human activity.

Data for stations 38 and 39 (Figs. 27 and 28) are not as complete as for the other stations. Also, they are located at the hydrographic extremes of the bay--station 38 at the end of the canal through which the Trinity River empties into Trinity Bay and station 39 at the mouth of Trinity Bay. Salinity fluctuations are similar at all these stations, except that salinity values at the upper bay station 25 lag about a month behind those at the other stations. Probable circulation patterns for Trinity Bay were observed in a scale model of the bay located at the U.S. Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi. Station 25 lies in a probable area of stagnation or backwater, which might allow for the lag in salinity increases and decreases.

There are no strong correlations between nutrient levels, dissolved oxygen, and salinity at stations 38 and 39, although high phosphate levels follow periods of high salinity or low river flow. Since Pullen, *et al.* (1971) states that higher concentrations of phosphates follow high river flow (in an earlier study), it is obvious that additional sampling is needed to define the exact relationship between river discharge and nutrient concentrations in the deeper center of the bay. Oxygen concentrations remained uniformly low throughout the sampling period at stations 38 and 39, a considerable departure from the behavior of DO at the other stations. It is possible that mixing processes are minimal at these two stations, because of their greater depths relative to the depths of the other stations. The Anahuac Channel is deeper than the surrounding bay, while station 39 is located at the deepest end of the bay. One anomaly appears in respect to salinity at station 38 in Anahuac Channel. This station is closest to the river mouth, yet salinities were higher there in the summer of 1970 than at any other of these Tracor stations. No explanation for this anomaly, other than the presence of a salt wedge in the channel, can be offered at this time. Salinity values at the mouth of the bay (station 39) also remain at high levels throughout 1970, but this might be expected if prevailing winds and the low runoff and rainfall favored the high influx of Gulf water into Galveston Bay proper.

In summary, salinity fluctuations correspond with each other at most of these six stations and if periods of low and high salinity are compared with river discharge (Fig. 20), it is obvious that a direct relationship exists between these two parameters in Trinity Bay. On the other hand, there is little correlation between river discharge and oxygen concentration. In addition, these recent data show that a rather weak relationship exists between nutrient concentrations and river discharge. Since we have already suggested that there are other sources for nutrients in Trinity Bay (other than river water), it is not going to be easy to determine the exact amounts of nutrients being brought down the Trinity

River, nor will it be possible to state the exact amount of discharge that should be allowed to reach the bay in order to insure proper fertilization of that estuary.

These graphically reproduced data from the Tracor study and the isoline maps of our own data do reveal that the whole bay tends to react to environmental changes as a single unit. A number of environmental parameters respond simultaneously to a single stimulus (high river discharge or an influx of salt water) throughout the bay. There is no question that vertical mixing is complete most of the time, as both temperatures and salinities are uniform throughout the water column in all areas. Horizontal mixing throughout Trinity Bay is relatively rapid, as was demonstrated for us by the Trinity Bay model at Vicksburg, Mississippi. Flushing may be accomplished in several tidal cycles, if no other forces other than hydraulic head from the Trinity River and tidal influx from the Gulf are to be considered. However, it has been our own experience in dealing with narrow river estuaries that flushing does not take place if the hydraulic head from river discharge is severely reduced (Parker, *et al.*, 1969). Water is sloshed back and forth by tidal motion and moves downstream to the estuary mouth only with the addition of water from upstream. We do not know at the present time if this phenomenon takes place in wide shallow estuaries such as Trinity Bay. It is evident that some measurements relating to total flushing in the bay should be made and possibly a computer model should be designed to take in the kinds of observations on tidal movements such as those made earlier on the Brazos and Colorado estuaries (Parker, *et al.*, 1969).

It is obvious from our cursory look at Trinity River circulation and hydrography that the placement of monthly sampling stations should be carefully planned in the light of what we have found concerning the different ecological niches and possible definable water masses. Future sampling stations should be selected so as to cover both shallow or near-shore habitats, and deep or bay center areas. Samples also should be collected over oyster reefs, within the river estuary itself, and within each of the three major types of marshes. It is only through broad synoptic coverage of stations taken frequently that a real understanding of the inner workings of the Trinity Bay major ecosystem will become possible.

In order to obtain a clearer picture of the water movements throughout Trinity Bay, we have included a map of the general circulation and net flow of water within Trinity Bay (Fig. 29). The arrows in this figure denote direction, but not absolute velocity. The circulation as presented is modified from original diagrams given by Bernard Johnson Engineers (1971), Tracor (1970), and Espey, *et al.* (1971). Our modifications were made after visiting the U.S. Corps of Engineers, Waterways Experiment Station, where we observed the scale model of Trinity Bay in operation. Using dye and confetti to illustrate the circulation in the bay, we were able to obtain a visual overall impression of water movement, which was photographed with a Polaroid camera. Circulation patterns were observed briefly through NASA Gemini photographs taken every hour for 24 hours. Unfortunately, copies of these photographs to be used for more concentrated studies were not obtained in time for the completion of this report.

The bay model observed in Vicksburg is a "windless" model, but apparently little consideration has been given to the effect of winds on the real Trinity Bay in past hydraulic research. Masch and Espey (1967) in their mathematical model of Galveston Bay claim that wind generated currents have little effect on the overall circulation. The winds are predominately from the south-southeast in the summer and north-northwest in the winter (Fig. 30). These winds are somewhat perpendicular to the longitudinal axis of the bay, so that the fetch is only about 13 miles. As a result of this rather short fetch, typical waves of Trinity Bay (as described by Lankford, *et al.*, 1969) are rather small, being 6 to 9 inches high, 10 to 15 feet in length, and having a period of between two and three seconds. However, during the three days of sampling by C.E.M., waves reached two to three feet in height every afternoon. These waves are probably only capable of mixing the waters in the bay and have little effect upon the general circulation. Wind as a factor influencing circulation at certain times of the year should not be ignored. Our own studies, re-enforced by Masch and Espey (1967), indicate that there should be no theoretical net effect of wind on Trinity Bay circulation if data for the wind rosettes (Galveston Bay) on Figure 30 are used for calculating circulation processes.

Studies of circulation in the shallow bays to the south of Galveston Bay indicate that winds are more important than tides in Texas bay circulation. The tidal diurnal range is less than a quarter of a foot along most of the Texas coast, whereas wind tides commonly raise bay levels four or five feet in most of the bays (Shepard, and Moore, 1960; Parker, 1959). In addition, Shepard and Moore (1960) state that water piles up on

Fig. 29. Generalized net flow and circulation patterns, Trinity Bay, Texas (Bernard Johnson Engineers, 1971; Tracor, 1970; and Espey, *et al.*, 1971).

LEGEND

⟶ Trinity River Flow

–·→ Houston Ship Channel Water

---→ Gulf Tidal Influx

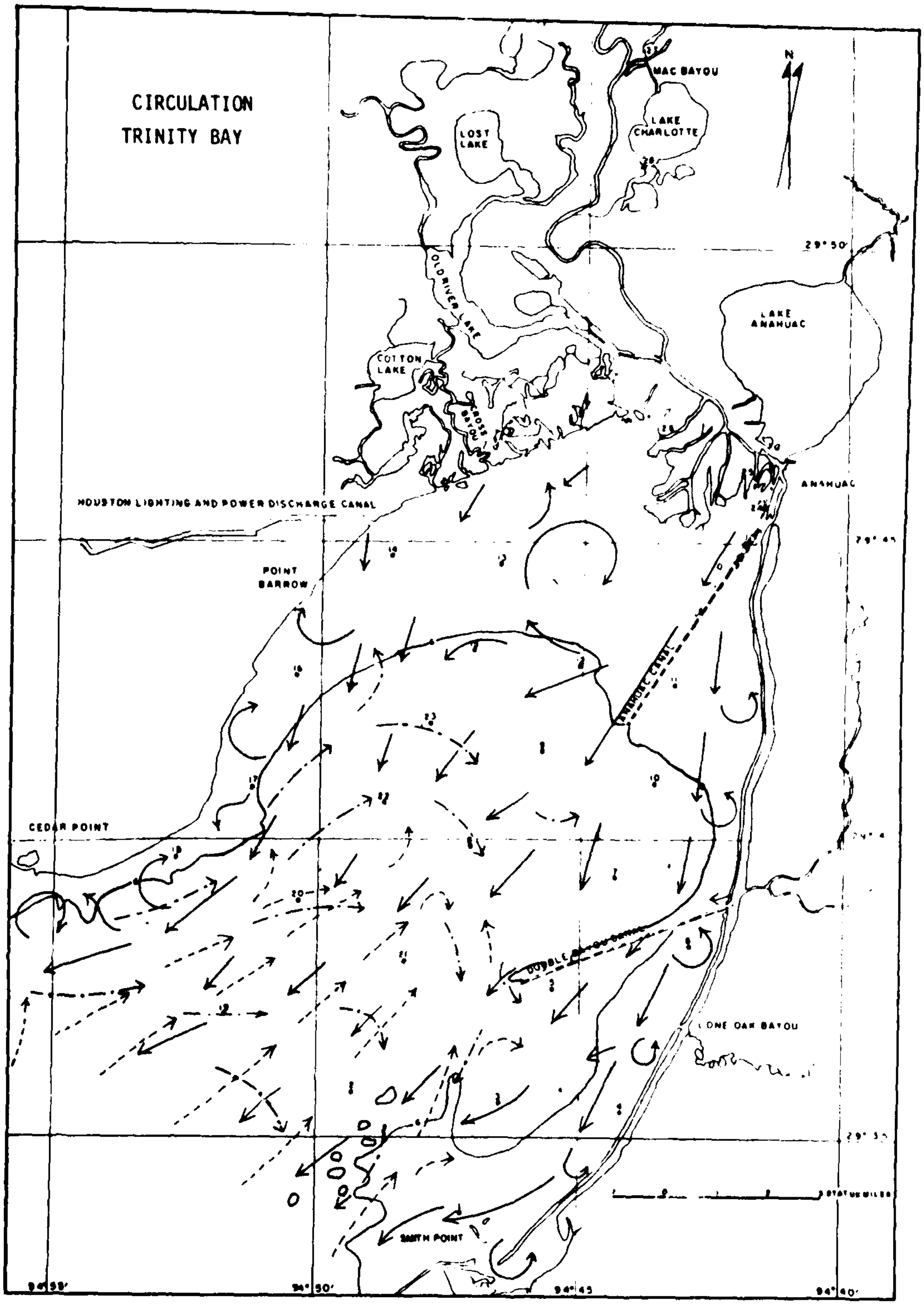
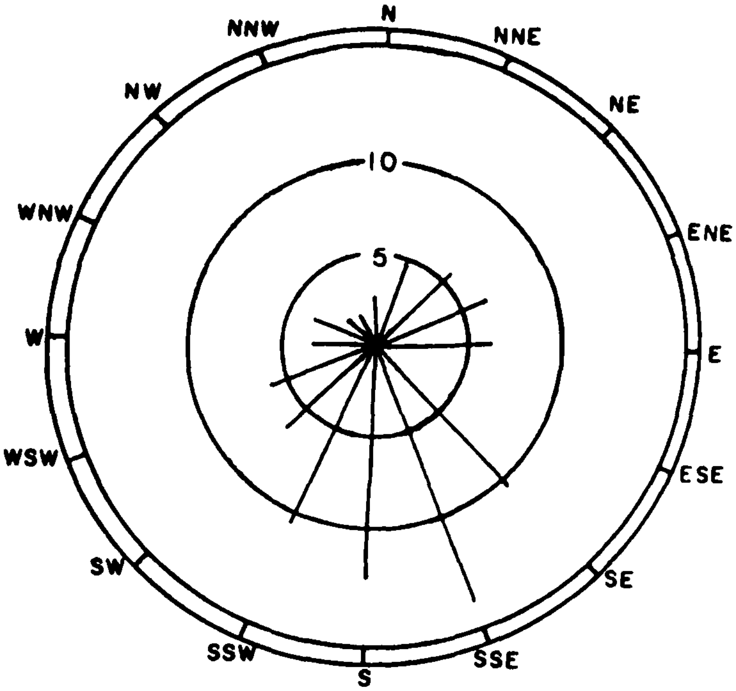

CIRCULATION
TRINITY BAY
MAC BAYOU
LAKE CHARLOTTE
LOST LAKE
OLD RIVER LAKE
LAKE ANAHUAC
COTTON LAKE
ANAHUAC
HOUSTON LIGHTING AND POWER DISCHARGE CANAL
POINT BARROW
CEDAR POINT
LONE OAK BAYOU
SMITH POINT
29°50'
94°55'
94°50'
94°45'
94°40'

Fig. 30. Wind rosettes - Galveston Bay, Texas.

A. % frequency of direction, August, 1970 (Tracor, 1970).

B. % frequency of direction x average speed, 1951-1960 (NOAA, 1970).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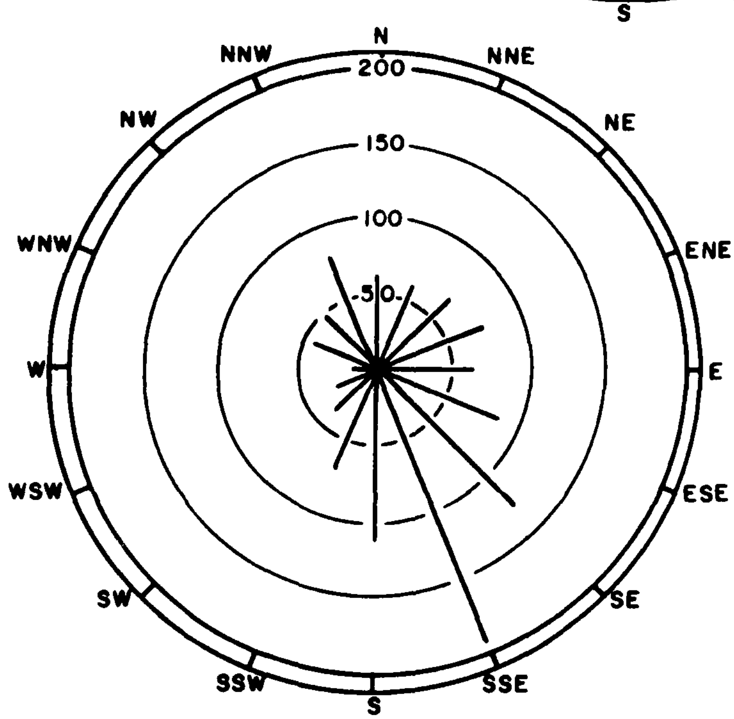
A.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NNW
200
150
100
50

B.

the north side of a bay during the southeast trades and on the southeast side during the northers. These winds may have a strong influence on inlet circulation (including the transfer of waters between Trinity Bay proper and the rest of Galveston Bay) and may account for the bulk of both water and sediment transport. These movements and forces have been largely ignored in both mathematical and physical models of Trinity Bay, since the annual net wind force and direction (Fig. 30) is considered to be ineffective in moving water in and out of Trinity Bay.

The remaining factor to be considered in determining the circulation of the bay is tidal currents. Lankford, *et al.* (1969) state that tidal currents (assuming astronomical ones only) transfer daily, in and out of Galveston Bay, almost three times the volume of the runoff of the Trinity and San Jacinto Rivers combined. The volume of water transferred by wind currents in and out of Bolivar Roads probably far exceeds the volume transported by astronomical tidal currents (Shepard, and Moore, 1960). The major portion of the waters brought in from the Gulf are transported into lower Galveston Bay and to the mouths of East and West Bays. According to the circulation diagram shown on Figure 29, the net transport of Gulf water is into the Trinity Bay entrance, where it is quickly dissipated within a few miles. The proposed "net" circulation probably masks the more important effects of water movement from wind tides. Most of the scour and transport of sediment out of Trinity Bay is probably accomplished by intermittent high wind tides, over which man has no control. The fact that the bay is continuing to deepen and the western edges of the bay to erode, regardless of river flow and diminution through impoundment, suggests that transport out of the bay must be through currents derived from both wind and astronomical tides. Comprehensive current studies in the field should be made to investigate this premise.

Movements of water from the Houston Ship Channel into Trinity Bay are also depicted on Figure 29. It would appear that a considerable amount of water is derived from the Houston Ship Channel (and San Jacinto River), most of which is distributed along the southwest side of the bay and for some distance up the center of the bay. The postulation of this circulation pattern is re-enforced by the pattern of distribution of the various environmental factors as shown on Figures 5 through 18. Although our circulation model does not provide data for velocities, the constriction of the bay at its mouth influences current strength in the direction of stronger currents. This is supported by the fact that virtually all of the living oyster reefs (Fig. 19) are located in and are aligned between the land points which form the mouth of Trinity Bay. These reefs grow perpendicular to predominate currents and do not flourish unless current strength is at a high, but yet undetermined optimum (Parker, 1959, 1960).

Each small point along the northwest and western side of Trinity Bay is the site of a small semi-permanent eddy. Similar eddies can also be found along the eastern shore. These too may be marked by small points, although they have been partially obliterated by the construction of the canal along the shore from Anahuac to Smith Point. These eddies appeared persistent and well-marked by turbidity plumes in the Gemini space photos. The fact that the eddies still occur on the eastern shore at points that no longer exist because of the Trinity Canal, suggests that they are not a result of the physiography but actually control it. Note that the Trinity River waters are distributed primarily on the east side (Fig. 29), as a net result of both hydraulic head and influx of Gulf and Houston Ship Channel water from the southwestern corner of the bay.

Observations made on the bay model at Vicksburg revealed that there is a previously unnoticed backwater just southwest of the Trinity delta in the northern corner of the bay. A slowly-moving clockwise eddy in this shallow corner of the bay tends to concentrate some environmentally produced substances into this backwater. This more or less currentless region receives most of the fine-grained suspended sediment load of the river and forms the basis for the pro-delta clay deposits as depicted by Fisher, *et al.* (1972) and in our Figure 19.

The circulation patterns on Figure 29 are reflected in some of the distribution patterns of other environmental parameters. The pattern of low values of nitrates plus nitrites as depicted in Figure 10 corresponds closely to the pattern of intrusion of Gulf waters (typically low in nitrogen) into the bay. The lower bacterial counts in the center of the bay (Fig. 14) might result from scouring by bottom currents in the deeper part of the bay. The salinity pattern in Figure 6 agrees well with the general circulation pattern, so far as indicating the paths of movement of both fresh and salt water masses. The high pH's (Fig. 7), turbidities (Fig. 8), mercury values (Fig. 9), and TOC's (Fig. 13) all appear to be associated with the flow of water coming into Trinity Bay from the Houston Ship Channel and the San Jacinto River.

An important fact relating to Trinity River discharge has apparently been overlooked by many authors. Lankford, *et al.* (1969) found that although the Trinity River flow into its estuary is one of the largest in Texas, nearly 20 percent of all the water flowing into Trinity Bay is derived from the last 45 miles of river drainage. Based on mean flow figures given in More (1965), the lower 45 miles of river contributes over a million acre feet of water annually, regardless of drought conditions in the upper drainage basin. This fact is extremely important, since it would appear that regardless of impoundments, such as Lake Livingston above Romayor (the last important gauging station on the Trinity), river discharge and its contained nutrients would be little effected by most of the river controls imposed by man upstream. On the other hand, the Wallisville impoundment is below Romayor, and could reduce this guaranteed freshwater flow into Trinity Bay considerably.

Throughout the 40 years of discharge measurements cited by More (1965), the mean annual flow of the Trinity River was 5.1 million acre feet/year. The volume of Trinity Bay is approximately 654,200 acre feet (Lankford, *et al.*, 1969) which means that under the 40 year conditions of river flow, the water in the bay was flushed out 7.8 times each year. Under the drought conditions of 1957 the flow of the Trinity River at Romayor dropped to 0.9 million acre feet (More, 1965) which was still enough to flush the bay 1 1/2 times that year. Perhaps 1.3 million acre feet or enough to flush the bay twice a year may be the minimum necessary to maintain the minimum levels of productivity in Trinity Bay.

According to some authors, any reduction in river flow into an estuary is going to increase salinities, vary the circulation of the bay, reduce the water level in the marshes, and reduce the rate of siltation in the bay (Diener, 1964). Copeland, *et al.* (1972) state that a reduction in flow is a reduction in nutrients and this is added stress to the upper estuary. A reduction in nutrients may result from two processes; first, if river inflow to Trinity Bay is reduced below the capacity to flush out or renew the water in the bay, that portion of the total nutrients supplied by the Trinity River will be reduced, while the nutrients entering the bay from the adjacent land and other sources will remain essentially unchanged. A second source of reduction in nutrients would be the increased amounts of Gulf water (typically low in nutrient ions) entering the bay. If Trinity River flow would be reduced below the level for effective flushing of the bay, there would be a considerable dilution of nutrients and consequently a large decrease in primary productivity in this bay. However, we have already stated that primary production seems to be more closely tied to the production of bacteria than to phytoplankton. In the event that phytoplankton productivity might be reduced as a result of low nutrient supply, there could be a reduction in the population of first order consumers that presently graze on phytoplankton and particulate organic matter supplied mostly from the river. Although it might be possible for the second level of the food chain, with no particulate organic matter to eat, to become solely dependent upon phytoplankton, the fact that such large bacterial populations already exist in this bay system suggest that lowered nutrient supplies from the river would not promote such a drastic outcome.

A PROGRAM FOR ADDITIONAL STUDIES ON TRINITY BAY BIOLOGICAL PRODUCTIVITY

Even though there has been considerable research performed on the ecology and hydrography of the Trinity River estuary over the past 10 or 15 years, it is apparent to us that some additional work should be carried out before final impact statements can be made for the entire Trinity canal system. First of all, a continuing program should be initiated for the monitoring of those factors concerned with primary biological production in Trinity Bay. We realize that there are several ongoing monitoring programs in both Trinity Bay and in other parts of the greater Galveston Bay system. However, these studies are concerned primarily with environmental variables that are associated with pollution from the Houston Ship Channel or Cedar Bayou region, and are not designed to solve problems associated with the Trinity River canal.

In order to provide definitive data on the amount of control that is needed to provide an adequate river discharge for sustained high biological productivity in Trinity Bay and Galveston Bay, a number of environmental parameters not measured in the past should be considered for future study. A monitoring study should be carried out every one or two months in three major environments: 1) the lower river below Lake Livingston, 2) all of the various marshes from strictly freshwater ones to those that are wholly marine, and 3) Trinity Bay, from the river mouth to the Houston Ship Channel. The lower river should be monitored as to data on tne amounts of precipitation, runoff, discharge, chemical constituents derived from land in the drainage area, concentrations of nutrients in the river, and silt load. Some of these variables are already measured by the U.S. Geological Survey at Romayor, but it will be necessary to obtain additional data for the 45 mile stretch to the bay.

An important part of this monitoring program should be the measurement of phytoplankton productivity, as $carbon^{14}$ uptake in photosynthesis. A series of stations for productivity measurements should be established in each of the different types of marshes and swamps, in various sections of the river, and throughout the bay. Bacterial populations should be counted in the water and sediments at all of the productivity stations. In addition to the productivity and bacterial studies, other levels of the food chain, such as zooplankton, benthic invertebrates, juvenile crustaceans, and larger nekton (swimming animals), should be studied. An accurate cover-map, as to the type of marsh (fresh, brackish, or marine), should be made of all marsh areas. Besides determining the overall marsh types, the exact floral composition and growth characteristics--perennial or annual, and rate of decomposition and renewal of marsh plants should also be established.

At the same time intensive studies are made of the productivity of the river and marshes, an intensive investigation of the factors governing primary production also should be made in Trinity Bay. These factors should include the measurements of the natural parameters of stress--temperature, pH, Mg/Ca, salinity, dissolved oxygen, and turbidity--plus selected parameters controlling primary productivity--nutrient concentrations, total organic carbon, and light production. In taking productivity measurements, light and dark bottle and $carbon^{14}$ uptake should be used. In a monitoring program designed to measure productivity, it is necessary to determine why respiration exceeds photosynthesis in Trinity Bay. Such a study would involve measuring zooplankton standing crops and availability of food for zooplankton. Permanent stations within the bay should be established according to habitat and within a sampling grid of one or two miles interval. A close-spaced sampling grid permits the computer plotting of variables in the same manner as shown on Figures 5 through 18.

One method for determining the river flow requirements for the bay would be to correlate river discharge with any one of a number of productivity indices; such as, $carbon^{14}$ uptake, diversity indices of plankton or benthos, and even the catch statistics of commercial seafood species. Eventually, it should be possible to determine an optimum discharge level for the maintenance of sufficient primary producers to sustain the food chain typical of an enclosed bay ecosystem. Special attention should be directed to the west side of the bay, in order to quantify the contribution of nutrients and other chemicals to the bay from the human populations there.

A substantiated and complete circulation pattern should be established through field measurements of current strength and direction during a full range of factors which can influence currents. An ideal current or circulation study should include both ground truth measurements and simultaneous remote sensing of the bay through high altitude and infrared photography. Synoptic patterns of circulation are possible through photographs of the whole bay at one time, and modifications of simple patterns at broad intervals of time can be realized through additional ground truth measurements at different discharge levels, tidal cycles, and wind stresses.

The establishing of such a monitoring program for a period of one year has considerable research potential. It is anticipated that this program could establish definitive relationships between the sources and metabolic pathways of nutrients in both the river and bay as they effect the eventual biological productivity in the entire Galveston Bay region. Eventually, nutrient/plankton and bacteria/organic matter relationships will be made clear enough to allow intelligent regulation of waters up-river in the Trinity drainage basin. A guaranteed optimum flow of water down the Trinity River will eventually establish stable and optimum levels of plants and animals needed for a smoothly operating ecosystem. The model established by this study could be extended to other estuaries along the Texas coast, leading to more stable and improved seafood production, and even increased recreational potentials.

A simple budget for the proposed one year monitoring program is submitted below in order to assist in future financial planning.

Direct Costs:

12 field trips (travel and per diem for a 4 man field party) @ $550/month	$ 6,600
Chemical analyses for 50 stations per month @ $1,000/month	12,000
Laboratory and field supplies @ $200/month	2,400
Salaries for three additional technicians @ $600/month/technician	21,600
Typing and publication costs for one year	6,000
Additional travel costs and insurance	5,000
Total Direct Costs	$53,600

Indirect Costs:

Administrative overhead at government approved rate of 43% of direct costs	$23,048
Total of overhead plus direct costs	$76,648
Fee, at 10% of overhead plus direct costs	7,665
Total Cost of a one year monitoring program	$84,313

SUMMARY AND CONCLUSIONS

A total of 28 stations were occupied in the Trinity Bay region for the purpose of assaying the factors responsible for maintaining basic primary productivity in Trinity Bay. A maximum of 24 major and 13 minor environmental variables were measured at each station, resulting in the acquisition of nearly 800 new data values for the estuary of the Trinity River.

Chemical-Physical Factors

1. Information gathered, not previously considered or collected in earlier studies, consisted of the measurements of calcium, magnesium, mercury, arsenic, total bacterial populations in water and sediments, primary productivity, turbidity, reduction-oxidation potentials (Eh), hydrogen sulphide, and precise sediment composition.

2. Values obtained on the early August field trip for the commonly measured factors, such as water temperature, salinity, dissolved oxygen, pH, nitrates plus nitrites, total organic carbon, phosphates, and benthic diversity, were well within the range of values obtained by earlier researchers. None of the values could be considered exceptionally high or low. Salinities were somewhat higher than the 20 year mean, which might account for higher pH's than usual for this estuary. These higher salinities also may reflect a trend towards increasing values dating from the impoundment of the Trinity River at

Lake Livingston.

3. The range of values of the four metallic ions from bottom water samples were not considered unusual for this environment. Mercury values were somewhat above the HEW acceptable levels for food in the portion of the bay closest to the Houston Ship Channel. The other three ions were in the normal range for most estuaries. The highest Mg/Ca were found at the mouth of the bay and the lowest values were measured in the upper river estuary. Arsenic values were uniformly low throughout the region.

4. Nitrate and nitrite concentrations measured in this study were well within the limits needed to sustain normal plant production (above 0.3 mg/l). Phosphate levels were greater than needed to supply the needs of growing plants, although Trinity Bay is characterized by a nitrogen/phosphorus (N/P) ratio of 1/10 instead of the 10/1, suggested as an optimum for plant growth. Eventually, this reversed ratio may become a limiting factor within the Trinity Bay ecosystem.

5. Total organic carbon values were typical of those measured in near-shore marine environments, although high TOC's were found in what could be identified as Houston Ship Channel water that had entered Trinity Bay.

Biological and Sediment Parameters

1. Bacterial counts for both water and sediment samples were exceptionally high, being nearly six orders of magnitude (a million times) larger than the minimum population of bacteria needed to exert an effect on an

aquatic ecosystem. Bacteria are more abundant in Trinity Bay than in the other six estuaries, where we have used the same techniques for counting bacteria. However, higher bacterial counts were found by another investigator in a study of the enormously productive grass flats of Redfish Bay, near Corpus Christi, Texas.

2. These exceptionally high bacterial populations in water and sediments of Trinity Bay lend support to the hypothesis that the production base for the food chain is bacterial production, with their ability to degrade the unusually high amounts of organic matter. Growth, reproduction, and replacement of most organisms in these warm, nutrient-rich waters is extremely rapid, and total production may be at one of the highest levels in the world.

3. Further support for this premise is the low standing crop of phytoplankton and zooplankton, and a tremendous population of larger benthonic and nektonic organisms, the majority of which are deposit feeders and scavengers. Turbidities are normally high throughout the year, as a result of fine material thrown into suspension by waves. For this reason, comparatively little sunlight penetrates the water to nourish plants or phytoplankton.

4. As the basis for food production in Trinity Bay may be the recycling of organic matter through a complicated bacterial cycle, it may not be necessary to impose rigid controls on river discharge upstream from Wallisville Lake in order to provide sufficiently high concentrations of plant nutrients.

5. The bacterial production cycle gains additional support as the base of the Trinity Bay food chain through evidence supplied by the benthic invertebrate studies. Total populations of invertebrates, larger than 250 microns and averaging 25,000 animals/m^2, were greater in Trinity Bay than in comparable habitats of other bays in Texas. Averages of invertebrate populations in different habitats, ranged from 1,700 animals/m^2 in clayey bottoms to 140,000 animals/m^2 on shelly bottom. Most of these animals feed on detritus within the sediment and would have to be supported by large populations of bacteria capable of converting organic carbon sources to food which will sustain deposit-feeding animals. These large numbers of small bottom-dwelling animals, in turn, furnish the food base for the larger and more active shrimp, crabs, and fish.

6. Benthic animal populations and species composition (not discussed in this paper) in Trinity Bay are closely correlated with sediment grain size. Detailed sediment analyses were made of surficial sediments. Small numbers of worms were associated with the finest clay sediments, while larger numbers of animals, composed of many species, were taken on mixed sand, silt and clay bottoms. Shell reefs produced the greatest number of animals.

7. High benthic animal diversity is associated with both stability and environmental predictability of an aquatic ecosystem. Overall diversity within the Trinity Bay region is low, as discovered from both our data and from those data taken by other investigators. Low faunal diversity in Trinity Bay can be attributed to the relatively

high fluctuations in salinity and temperature throughout the year. What is more important in reducing normal animal diversity in this bay, is that the environmental fluctuations are mostly at the minimum levels for survival of marine and wholly freshwater organisms. Few animal species can tolerate salinities that vary constantly between 1 $^{o}/oo$ and 15 $^{o}/oo$. The most stable portions of Trinity Bay are in the deeper parts of the bay, which were characterized by the highest diversity indices.

8. Although low diversity indices (below 3) are characteristic of high to moderate industrial pollution, it is more than likely that our low DI's in the vicinity of the river mouth are more related to natural stress conditions typical of this habitat.

9. The present distribution of sediments in Trinity Bay reflect normal estuarine circulation and wave characteristics. Coarse sediments are concentrated along the shore to depths below the wave base (about six feet), while fine sediments characterize the bay center. The finest sediments were found at the mouths of the small bayous and in the backwaters or settling basins of the Trinity delta. Further reduction of the river discharge may cause a shift in the pattern of sediment types. A reduction of sediment supply might hasten the erosion already evident along the western shore of the bay.

10. Data from an earlier study revealed that Trinity Bay has deepened significantly in the past 100 years. Only one other bay in Texas, Corpus Christi Bay, has deepened rather than shoaled during this

period. At least 20% of the deepening has occurred in the last 20 years, so that the rate appears to be relatively uniform, regardless of the impoundments placed upstream in the drainage basin. These data suggest that deposition from suspended sediment load from the river is not sufficient to keep pace with tidal scour. If little sediment now reaches the bay, it is possible that the nutrient supply to Trinity Bay is small also. Subsidence may be a factor too.

Factors Controlling Productivity in Trinity Bay

1. One of the most important factors controlling plant productivity is the availability of nutrient ions--nitrate, nitrite, and phosphate. Of these three ions, nitrate is the most limiting one. Research indicates that the amount of nitrates in the nearest impoundment, Lake Livingston, is already low. Nitrate values in Trinity Bay and the lower Trinity River estuary for the past four years were also low, but capable of sustaining a minimum phytoplankton population.

2. Phosphate levels are ten times those of nitrates plus nitrites and could eventually inhibit productivity if allowed to increase. One reason for the excess of phosphate over nitrate is the rate of utilization of these nutrients by aquatic plants. Apparently, nitrogen is recycled 26 times faster than phosphorus and carbon is used up at a rate 126 times faster than phosphorus. Nitrate is also extremely soluble and has no reservoir in the sea. Since phosphate is recycled slowly, its concentration in Trinity Bay can be expected to exceed that of nitrate.

3. The ratio of respiration to photosynthesis is used as an indicator of the autotrophic or heterotrophic nature of an aquatic community. If the P/R is greater than one (photosynthesis exceeds respiration), the community is based on an autotrophic metabolism. Studies indicate that the P/R of Trinity Bay is less than one, and is between 43 and 72 percent dependent upon organic matter to support a higher level of secondary productivity.

4. The source of organic matter needed to sustain the heterotrophic (high respiration over photosynthesis) nature of the food chain in Trinity Bay can be hypothesized as the tremendous populations of crabs, shrimp, worms, and fish which feed primarily on degraded organic matter, or those organisms which feed directly on organic detritus. The recycling of this abundant supply of protein could be the source of primary production aided by the degradation processes of the abnormally high bacterial populations.

5. Another source of organic matter could be the carbon-rich waters of the Houston Ship Channel. By the time the carbon-laden waters of the ship channel reach the center of Trinity Bay (as reflected by the turbidity and TOC patterns) they may be cleansed of the toxins and inhibitors of life which characterize them while in the channel. Carbon sources from this water could easily support a large bacterial population.

6. Regardless of the fact that respiration exceeds photosynthesis in Trinity Bay, phytoplankton production is still relatively high compared

to open ocean and continental shelf waters. On the other hand, there is a production deficit of plants and an under-utilization of nutrients. There are indications that phytoplankton production may actually be inhibited by some factors not yet investigated.

Hydrology as a Factor Controlling Productivity

1. If the Trinity River is the sole source of nutrients needed to sustain primary production in Trinity Bay, the importance of controlling the amount of water which reaches the bay can never be overestimated. It has already been demonstrated that sources, other than the river, supply both nutrients and primary production for the bay. However, if nutrients and carbon sources are removed from the bay by some means--such as overfishing--a continued supply of freshwater would be a necessity.

2. A salinity gradient is one factor needed to sustain a high yield of larger organisms in Trinity Bay. Previous studies showed that a direct relationship exists between river discharge and the salinity gradient from river mouth to gulf. When discharge is low, a sharp gradient of low to high salinity exists within the bay. When discharge is high, a gradual gradient, marked by slowly increasing salinities from river mouth to Galveston Bay, is present.

3. Trinity Bay is a nutrient trap; so that when discharge is low, nutrients tend to be more concentrated in the river and reach the bay in a higher concentration. When discharge is high, the same or slightly larger amounts of nutrients which had occurred at low discharge are

present in the river, but are diluted by river water. Nevertheless, all the nutrients still reach the bay, where they can accumulate at the same rate as before. Because the bay is a trap for nutrients, regardless of discharge, little correlation can be found over the years between nutrient concentrations in the river and the bay as a function of river discharge.

4. The relationships between salinity, nutrient levels, dissolved oxygen, and river discharge were examined in detail through the graphing of data collected monthly over two annual cycles by Tracor, Inc. Data from six Trinity Bay stations, three close to shore and three in the deeper part of the bay, indicated that separate water masses may be a real feature in the bay.

5. Seasonal variations in dissolved oxygen were closely associated with water temperature, which is to be expected, since the solubility of oxygen is temperature dependent. Highest nitrate values were correlated with salinity and runoff or river discharge. Lowest phosphate values occurred simultaneously with highest salinities, since gulf waters are naturally low in phosphate and dilute the bay waters by their presence. Only a weak correlation existed between nutrient levels in general and river discharge, supporting our contention that control of river water may not be important in maintaining bay biological productivity.

6. The most important fact derived from the graphing of data from the six Tracor stations was that although there appears to be some evidence of

separate water masses within the bay, the entire bay reacts as a whole to major changes in environmental conditions. A number of factors respond simultaneously to a single stimulus, such as high river discharge or influx of salt water. Apparently, both horizontal and vertical mixing are rapid in this broad shallow bay.

7. A "windless" circulation diagram for Trinity Bay was compiled from various sources, including the Tracor computer model, a scale model of the bay at Vicksburg, Mississippi, and our own observations and speculations. According to a wind rosette, compiled from a half century of averages, wind would appear to have little effect upon circulation, and waves have even less an effect. Winds are nearly perpendicular to the long axis of the bay, and theoretically have too short a fetch to create either high waves or major circulation features. However, studies of circulation in other Texas bays indicate that winds are responsible for most of the net water movement in and out of the bay. Astronomical tides are normally less than a quarter of a foot in amplitude, while normal onshore winds may raise water levels four or five feet within a bay.

8. It is possible for three times the volume of the Trinity and San Jacinto Rivers to be moved in and out of Galveston Bay by astronomical tides alone. The volume of water transported by wind forces is even greater. Most of the aforementioned scour in Trinity Bay is probably accomplished by wind tides, rather than the flow of Trinity River. Since the flushing of Trinity Bay is more likely to be accomplished by tidal motions than by river discharge, the importance of the Trinity

River is lessened further as a force in influencing major biological production in the bay.

9. The circulation pattern proposed by us suggests that both environmental factors and biotic variables are influenced greatly by water movements within the bay. It has been our contention for many years that circulation plays the principal role in determining the composition and distribution of animal and plant communities in shallow waters throughout the world. Water movements shape the physiography or geomorphology of the bottom and shoreline, bring nutrients to fixed plants, and distribute the planktonic larvae of bottom living animals.

10. In the case of Trinity Bay, circulation distributes nutrients, controls the sizes of sediment bacterial populations, influences the distribution of salinity; and through the movements of the Houston Ship Channel water into the bay, transports some pollutants and considerable organic carbon up into the bay.

11. Of prime importance to this study is the fact that 20 percent of the entire flow of the Trinity River is derived from the last 45 miles of the drainage basin. This lower 45 miles of river brings a minimum of a million acre feet of water per year into Trinity Bay, regardless of rainfall or runoff in the upper drainage basin. Since this portion of the river is below all of the Trinity reservoirs, except the proposed Wallisville Lake, the establishment of the Trinity River canal and its locks upstream should have little overall effect upon the minimum discharge of the river.

12. A little less than a million acre feet per year of Trinity River water is sufficient to flush Trinity Bay completely, one and a half times a year. Calculations indicate that about 1.3 million acre feet of Trinity River water, or enough to flush the bay at least twice a year, could be sufficient to nourish and maintain the minimum levels of phytoplankton production each year. This amount of water can be supplied entirely by the drainage area below Lake Livingston. On the other hand, will the impoundment of water behind Wallisville Lake cut this minimum 1.3 million acre feet of Trinity water to a level which would be insufficient to support a sustaining phytoplankton production?

13. A reduction in nutrients to dangerous levels could result from two processes: 1) the river flow could be reduced beyond the capacity for it to flush the bay, thus reducing the source of nutrients; and 2) saltwater from the gulf could predominate within the bay, and being normally low in nutrients, dilute the already nutrient-poor bay water. However, the fact that such large bacterial populations already exist in this bay system suggest that the lowering of phytoplankton nutrient supplies may not be such a catastrophe.

A Monitoring Program for Additional Trinity Bay Studies

1. Finally, a one-year program for monitoring the biological and chemical factors regulating primary production in Trinity Bay is proposed. A 50-station sampling grid should be established throughout the river estuary, the various types of marshes, and on a one or two mile

interval grid in Trinity Bay. Environmental factors which have been ignored in the past monitoring projects should be emphasized. These factors include measurements of primary plant productivity, total bacterial populations in the waters and sediments, quantitative evaluations of other larger trophic levels, and all nutrient factors, including vitamin B_{12} concentrations. Natural parameters of stress, which govern the overall ecosystem, should be measured at the same time that the biological factors are examined.

2. This monitoring program could establish definitive relationships between nutrient sources and levels as they effect greater metabolic pathways in the entire Galveston Bay system. Results of this study can be used to design an intelligent water regulatory program for waters throughout the Trinity River canal. Eventually, a stable and optimum set of conditions can be established for a smoothly operating bay ecosystem. The study could function as a model for other estuaries along the Gulf coast, leading to a more stable and improved seafood production and increased recreational potential.

3. The total cost for a one-year monitoring program in the Trinity estuary region would amount to approximately $85,000.

RECOMMENDATIONS

1. Maintain a vigil against the increase of phosphate in Trinity Bay. Higher levels than now exist in the bay may inhibit plant production, because nitrate and nitrite levels are already too low in relation to phosphate concentrations.

2. Insure that a sufficient river discharge is maintained so that a salinity gradient will exist from river mouth to bay mouth. Some of the commercially important species of shellfish and fish need low salinities at certain stages of their life histories for added protection against high salinity preferring predators.

3. Permit at least 1,300,000 acre feet of water to be discharged into Trinity Bay. This amount will flush the bay twice a year and may guarantee sufficient nutrients to sustain a minimum phytoplankton and marsh plant production in the region. This volume of water can be supplied from the last 45 miles of the Trinity River drainage basin, if water is not entirely withheld by Wallisville Lake levees.

4. A minimum of a one-year environmental monitoring program should be established to acquire the necessary data for continued management of the river discharge needed to maintain productivity in Trinity Bay. This minimum one-year monitoring program for the Trinity Bay estuary will cost approximately $85,000. The U.S. Army Corps of Engineers must act in a conservative manner in regard to making any alterations

of river flow into the Galveston Bay system, until more definitive data on the contribution that this river makes to bay productivity becomes available.

5. The U.S. Corps of Engineers should fully evaluate all hurricane protection levee systems and tidal exchange structures surrounding the Galveston Bay area before any proposed alterations of the Trinity River flow are made. The present levee system and other tidal exchange structures serve to reduce tidewater exchange and alter the bay circulation system. Further restriction of tidal flow into and out of the bay may greatly increase the future stability of the bay ecosystem.

6. Trinity Bay may be showing some evidence of pollution from the increasing population along the west side of the bay and certainly from the discharge of the Houston Lighting and Power Company coolant canal. In the interests of preserving the environmental "health" of Trinity Bay, it is recommended that the Corps of Engineers survey all county and municipal waste disposal criteria for those communities and counties adjacent to the bay in order to determine whether there is a need for a stricter pollution code or stricter enforcement of the present code. Adherence to these codes would prevent further deterioration of the water quality in Trinity Bay.

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APPENDIX I

C.E.M. STATION DATA SHEET

PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Miller, Parker

STATION: TB-1 DATE: 1 VIII 72 TIME: 8:18 to 9:00 DEPTH: 4 1/2 ft.

LOCATION: Lat. 29° 33' 40" N Long. 94° 47' 10" W

WIND SPEED: 5 mph WIND DIRECTION: SW

PARAMETERS:	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	29°C.	25.8°C.	
Turbidity (JTU):		--	
Salinity (o/oo):			15.6
Clorinity: (o/oo)			14.3
pH:			8.3
Eh (MV):			--
O_2 (ppm): Light Bottle:		Dark Bottle:	14
Nitrate plus Nitrites (ppm)--corrected:			.04
Orthophosphate (ppm)--corrected:			--

BIO-SAMPLE COLLECTING DEVICES: Van Veen grab 1/25 m^2; plankton net--qualitative, 3 minutes.

BIO-DATA REMARKS: Grab--shell bottom--. Old shell covered with bryozoa, barnacles, and algae. Mullet

CORE SAMPLE: No core--shell CORE DEVICE: Plastic tube

TYPES OF SAMPLES TAKEN: Biology: X

Chemistry:

Hydrocarbons: ____

Trace Metals: X

Nutrients: X

Microbiology: X

Sediment: none-shell

REMARKS:

Plankton, Ctenophores

Surface H_2S: 0.1 ppm

C.E.M. STATION DATA SHEET

PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Miller, Parker

STATION: TB-2 DATE: 1 VIII 72 TIME: 9:00 to 9:30 DEPTH: 9 1/2 ft

LOCATION: Lat. 29° 35' 50" N Long. 94° 49' 35" W

WIND SPEED: 4.5 mph WIND DIRECTION: SW

PARAMETERS:	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	28.2°C.	27.2°C.	
Turbidity (JTU):		--	
Salinity (o/oo):			17.0
Clorinity: (o/oo)			15.7
pH:			8.1
Eh (MV):			--
O_2 (ppm): Light Bottle: 20		Dark Bottle: 14	15
Nitrate plus Nitrites (ppm)--corrected:			.05
Orthophosphate (ppm)--corrected:			1.0

BIO-SAMPLE COLLECTING DEVICES: Van Veen; plankton net, 3 minutes

BIO-DATA REMARKS: School-bay-Menhaden; Brevoortia; light and dark productivity sample

CORE SAMPLE: CORE DEVICE: core in Van Veen

TYPES OF SAMPLES TAKEN: Biology: ________

Chemistry:

Hydrocarbons: ____

Trace Metals: X

Nutrients: X

Microbiology: X

Sediment: ________

REMARKS: Gray silty clay

Service H_2S: 0.1 ppm

C.E.M. STATION DATA SHEET

PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Miller, Parker

STATION: TB-3 DATE: 1 VIII 72 TIME: 9:37-9:55 DEPTH: 9 1/2 ft.

LOCATION: Lat. 29° 35' 35"N Long. 94° 46' 45" W

WIND SPEED: 6.5 mph WIND DIRECTION: SW

PARAMETERS:	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	28.2°C.	27.4°C.	
Turbidity (JTU):		--	
Salinity (o/oo):			16.9
Clorinity: (o/oo)			15.5
pH:			8.05
Eh (MV):			229

O_2 (ppm): Light Bottle: Dark Bottle:	17 (#11)
Nitrate plus Nitrites (ppm)--corrected:	0.06
Orthophosphate (ppm)--corrected:	0.3

BIO-SAMPLE COLLECTING DEVICES: Van Veen grab, good; plankton net, 3 minutes.

BIO-DATA REMARKS: Mullet

CORE SAMPLE: CORE DEVICE: Core in Van Veen

TYPES OF SAMPLES TAKEN: Biology: X

Chemistry:

Hydrocarbons: ____

Trace Metals: X

Nutrients: X

Microbiology: X

Sediment: X

REMARKS: Silty Clay

Surface H_2S: 0.1 ppm

C.E.M. STATION DATA SHEET
PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Miller, Parker
STATION: TB-4 DATE: 1 VIII 72 TIME: 10:12 to 10:27 DEPTH: 2 1/2 ft.
LOCATION: Lat. 29° 35' 25" N Long. 94° 44 15" W

Off Hodges Reef

WIND SPEED: 8-10 mph WIND DIRECTION: S

PARAMETERS:	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	27.1°C.	27.5°C.	
Turbidity (JTU):		--	
Salinity (o/oo):			15.9
Clorinity: (o/00)			14.6
pH:			8.0
Eh (MV):			209
O_2 (ppm): Light Bottle: 20	Dark Bottle: 15		18
Nitrate plus Nitrites (ppm)--corrected:			0.058
Orthophosphate (ppm)--corrected:			0.8

BIO-SAMPLE COLLECTING DEVICES: Van Veen, 1/25 m^2; plankton net, 3 minutes.

BIO-DATA REMARKS: Ctenophores in plankton; oyster reef bottom; name Hodges Reef; light and dark productivity taken.

CORE SAMPLE: 25 cm CORE DEVICE: plastic push core

TYPES OF SAMPLES TAKEN: Biology: X
Chemistry:
Hydrocarbons: ____
Trace Metals: X
Nutrients: X
Microbiology: X
Sediment: X

REMARKS: Fine sandy bottom; silty sand.

Surface H_2S: 0.1 ppm

C.E.M. STATION DATA SHEET

PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Miller

STATION: TB-5 DATE: 1 VIII 72 TIME: 10:55-11:10 DEPTH: 9 ft.

LOCATION: Lat. 29° 37' 35" N. Long. 94° 45' 35" W.

End Double Bayou Channel Marker # 2

WIND SPEED: 6.5 mph WIND DIRECTION: S

PARAMETERS:	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	33.4°C.	27.0°C	
Turbidity (JTU):		23	
Salinity (o/oo):			16.3
Clorinity: (o/oo)			15.0
pH:			8.3
Eh (MV):			229
O_2 (ppm): Light Bottle:		Dark Bottle:	30
Nitrate plus Nitrites (ppm)--corrected:			0.048
Orthophosphate (ppm)--corrected:			0.89

BIO-SAMPLE COLLECTING DEVICES: Van Veen; plankton, 3 minutes

BIO-DATA REMARKS: Nothing much

CORE SAMPLE: CORE DEVICE: Van Veen core

TYPES OF SAMPLES TAKEN: Biology: X

Chemistry:

Hydrocarbons: ____

Trace Metals: X

Nutrients: X

Microbiology: X

Sediment: X

REMARKS: Silty clay

Surface H_2S: 0.1 ppm

C.E.M. STATION DATA SHEET

PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Miller, Parker

STATION: TB-6 DATE: 1 VIII 72 TIME: 11:30 DEPTH: 7 1/2 ft.

LOCATION: Lat. 29° 38' 20" N Long. 94° 43' 00" W

Outside Double Bayou Channel at Marker 12

WIND SPEED: 6 mph WIND DIRECTION: S

PARAMETERS:	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	30°C.	27.8°C.	
Turbidity (JTU):		19.2	
Salinity (o/oo):			15.6
Clorinity: (o/oo)			14.3
pH:			7.9
Eh (MV):			259
O_2 (ppm): Light Bottle:		Dark Bottle:	8
Nitrate plus Nitrites (ppm)--corrected:			0.065
Orthophosphate (ppm)--corrected:			0.88

BIO-SAMPLE COLLECTING DEVICES: Van Veen Grab; plankton

BIO-DATA REMARKS:

CORE SAMPLE: 10 cm CORE DEVICE: plastic tube corer

TYPES OF SAMPLES TAKEN: Biology: X

Chemistry:

Hydrocarbons: ____

Trace Metals: X

Nutrients: X

Microbiology: X

Sediment: X

REMARKS: Clayey silt to sand silt clay

Surface H_2S: 0.1 ppm

C.E.M. STATION DATA SHEET

PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Miller, Parker

STATION: TB-7 DATE: 1 VIII 72 TIME:14:40-14:50 DEPTH: 8 1/2 ft.

LOCATION: Lat. 29° 39' 25" N Long. 94° 44' 25" W

WIND SPEED: 10-12 mph WIND DIRECTION: S

PARAMETERS:	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	35°C	28°C	
Turbidity (JTU):		13	
Salinity (o/oo):			15.7
Clorinity: (o/oo)			14.4
pH:			7.8
Eh (MV):			--
O_2 (ppm): Light Bottle: 23		Dark Bottle: 13	36
Nitrate plus Nitrites (ppm)--corrected:			.065
Orthophosphate (ppm)--corrected:			0.91

BIO-SAMPLE COLLECTING DEVICES: Van Veen; plankton

BIO-DATA REMARKS: None; light and dark productivity taken

CORE SAMPLE: CORE DEVICE: Van Veen

TYPES OF SAMPLES TAKEN: Biology: X

Chemistry:

Hydrocarbons: ____

Trace Metals: X

Nutrients: X

Microbiology: X

Sediment: X

REMARKS:

Surface H_2S: 0.1 ppm

C.E.M. STATION DATA SHEET

PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Miller, Parker

STATION: TB-8 DATE: 1 VIII 72 TIME: 15:07-15:20 DEPTH: 9 ft.

LOCATION: Lat. 29° 39' 50" N. Long. 94° 47' 10" W

WIND SPEED: 14-16 mph WIND DIRECTION: S

PARAMETERS:	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	--	--	
Turbidity (JTU):		21	
Salinity (o/oo):			14.9
Clorinity: (o/oo)			13.6
pH:			7.5
Eh (MV):			249

O_2 (ppm): Light Bottle: Dark Bottle: 14

Nitrate plus Nitrites (ppm)--corrected: .06

Orthophosphate (ppm)--corrected: 0.92

BIO-SAMPLE COLLECTING DEVICES: Van Veen; plankton

BIO-DATA REMARKS: Van Veen, plankton, pro delta silty clay

CORE SAMPLE: CORE DEVICE: Van Veen

TYPES OF SAMPLES TAKEN: Biology: X

Chemistry:

Hydrocarbons: ____

Trace Metals: X

Nutrients: X

Microbiology: X

Sediment: X

REMARKS:

Surface H_2S: 0.1 ppm

C.E.M. STATION DATA SHEET
PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Miller, Parker
STATION: TB-9 DATE: 1 VIII 72 TIME: 15:35-15:47 DEPTH: 9 ft.
LOCATION: Lat. 29° 41' 30" N Long. 94° 45' 35" W

3 miles on course; 25° from TB-8

WIND SPEED: 16 mph WIND DIRECTION: S

PARAMETERS:	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	31°C.	28°C.	
Turbidity (JTU):		30	
Salinity (o/oo):			13.3
Clorinity: (o/oo)			12.2
pH:			7.9
Eh (MV):			249
O_2 (ppm): Light Bottle:		Dark Bottle:	19
Nitrate plus Nitrites (ppm)--corrected:			0.115
Orthophosphate (ppm)--corrected:			0.80

BIO-SAMPLE COLLECTING DEVICES: Van Veen

BIO-DATA REMARKS: None

CORE SAMPLE: CORE DEVICE: Van Veen

TYPES OF SAMPLES TAKEN: Biology: X
Chemistry:
Hydrocarbons: ___
Trace Metals: X
Nutrients: X
Microbiology: X
Sediment: X

REMARKS:

Surface H_2S: 0.1 ppm

C.E.M. STATION DATA SHEET
PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Miller, Parker
STATION: TB-10 DATE: 1 VIII 72 TIME: 16:07 DEPTH: 7 ft.
LOCATION: Lat. 29° 41' 00" N Long. 94° 43' 45" W

1 mile off Black Point; 2 miles north of Oak Island

WIND SPEED: 16-17 mph WIND DIRECTION: S

PARAMETERS:	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	32°C.	29°C.	
Turbidity (JTU):		28	
Salinity (o/oo):			14.4
Clorinity: (o/oo)			13.2
pH:			7.9
Eh (MV):			249
O_2 (ppm): Light Bottle:		Dark Bottle:	14
Nitrate plus Nitrites (ppm)--corrected:			0.075
Orthophosphate (ppm)--corrected:			0.68

BIO-SAMPLE COLLECTING DEVICES: Van Veen; plankton

BIO-DATA REMARKS:

CORE SAMPLE: CORE DEVICE: Van Veen

TYPES OF SAMPLES TAKEN: Biology: X
Chemistry:
Hydrocarbons: ____
Trace Metals: X
Nutrients: X
Microbiology: X
Sediment: X

REMARKS:

Surface H_2S: 0.1 ppm

C.E.M. STATION DATA SHEET
PROJECT: Trinity Bay PERSONNEL: Smith. Solomon, Miller, Parker
STATION: TB-11 DATE: 1 VIII 72 TIME: 16:25 DEPTH: 4 1/2 ft.
LOCATION: Lat 29° 42' 40" N Long. 94° 43' 25" W

Just south 100 yards; Marker #1 on Anahuac Channel - Trinity River

WIND SPEED: 16-18 mph WIND DIRECTION: S

PARAMETERS:	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	31°C.	28.5°C	
Turbidity (JTU):		30	
Salinity (o/oo):			12.6
Clorinity: (o/oo)			11.5
pH:			7.8
Eh (MV):			209
O_2 (ppm): Light Bottle:		Dark Bottle:	18.5
Nitrate plus Nitrites (ppm)--corrected:			0.055
Orthophosphate (ppm)--corrected:			0.78

BIO-SAMPLE COLLECTING DEVICES: Van Veen

BIO-DATA REMARKS:

CORE SAMPLE: 40 cm CORE DEVICE: Push core

TYPES OF SAMPLES TAKEN: Biology: X
Chemistry:
Hydrocarbons: ____
Trace Metals: X
Nutrients: X
Microbiology: X
Sediment: X

REMARKS:

Surface H_2S: 0.1 ppm

C.E.M. STATION DATA SHEET

PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Miller, Parker

STATION: TB-12 DATE: 1 VIII 72 TIME: 16:57 DEPTH: 8 1/2 ft.

LOCATION: Lat. 29° 43' 05" N Long. 94° 45' 05" W

1 1/2 miles, course 315° from Marker #1 Anahuac Channel, Trinity River.

WIND SPEED: 14-15 mph WIND DIRECTION: S

PARAMETERS:	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	29°C.	28°C	
Turbidity (JTU):		29	
Salinity (o/oo):			11.8
Clorinity: (o/oo)			10.8
pH:			8.0
Eh (MV):			249
O_2 (ppm): Light Bottle:		Dark Bottle:	18
Nitrate plus Nitrites (ppm)--corrected:			--
Orthophosphate (ppm)--corrected:			0.86

BIO-SAMPLE COLLECTING DEVICES: Van Veen; plankton

BIO-DATA REMARKS:

CORE SAMPLE: CORE DEVICE: Van Veen

TYPES OF SAMPLES TAKEN: Biology: X

Chemistry:

Hydrocarbons: ____

Trace Metals: x

Nutrients: X

Microbiology: X

Sediment: X

REMARKS:

Surface H_2S: 0.1 ppm

C.E.M. STATION DATA SHEET

PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Miller, Parker

STATION: TB-13 DATE: 2 VIII 72 TIME: 08:22-08:37 DEPTH: 6 ft.

LOCATION: Lat. 29° 44' 45" N Long. 94° 46' 30" W

NE of Houston Lighting and Power Canal in corner of bay

WIND SPEED: 6 mph WIND DIRECTION: S

PARAMETERS:	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	27.3°C	28°C	
Turbidity (JTU):		36	
Salinity (o/oo):			14.0
Clorinity: (o/oo)			12.8
pH:			7.0
Eh (MV):			179
O_2 (ppm): Light Bottle:		Dark Bottle:	12
Nitrate plus Nitrites (ppm)--corrected:			0.14
Orthophosphate (ppm)--corrected:			1.6

BIO-SAMPLE COLLECTING DEVICES: Van Veen; plankton

BIO-DATA REMARKS: Dark and light bottle productivity taken -- values questionable

CORE SAMPLE: 15 cm CORE DEVICE: Core tube

TYPES OF SAMPLES TAKEN: Biology: X

Chemistry:

Hydrocarbons: ____

Trace Metals: X

Nutrients: X

Microbiology: X

Sediment: X

REMARKS:

Surface H_2S: <0.1 ppm

C.E.M. STATION DATA SHEET

PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Miller, Parker

STATION: TB-14 DATE: 2 VIII 72 TIME 08:50-09:05 DEPTH: 3 ft.

LOCATION: Lat. 29° 44' 55" N Long. 94° 48' 35" W

Just 1/2 mile off Houston Lighting and Power canal entrance

WIND SPEED: 7 mph WIND DIRECTION: S

PARAMETERS:	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	28°C	28.4°C.	
Turbidity (JTU):		8	
Salinity (o/oo):			17.0
Clorinity: (o/oo)			15.6
pH:			7.5
Eh (MV):			129
O_2 (ppm): Light Bottle:		Dark Bottle:	12
Nitrate plus Nitrites (ppm)--corrected:			0.29
Orthophosphate (ppm)--corrected:			1.95

BIO-SAMPLE COLLECTING DEVICES: Van Veen

BIO-DATA REMARKS: Clear water; lots of fishermen

CORE SAMPLE: CORE DEVICE: Corer

TYPES OF SAMPLES TAKEN: Biology: X

Chemistry:

Hydrocarbons: ____

Trace Metals: X

Nutrients: X

Microbiology: X

Sediment: X

REMARKS:

Surface H_2S: <0.1 ppm

C.E.M. STATION DATA SHEET

PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Miller, Parker

STATION: TB-15 DATE: 2 VIII 72 TIME: 08:00-08:15 DEPTH: 8 1/2 ft.

LOCATION: Lat. 29° 43' 20" N Long. 94° 47' 05" W

Offshore off Houston Lighting and Power Canal due west Marker #1

WIND SPEED: 7 mph WIND DIRECTION: S

PARAMETERS:

	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	26.5°C.	27.8°C.	
Turbidity (JTU):		38	
Salinity (o/oo):			15.7
Clorinity(o/oo):			14.4
pH:			8.2
Eh (MV):			139
O_2 (ppm): Light Bottle: Dark Bottle:			13
Nitrate plus Nitrites (ppm)--corrected:			.09
Orthophosphate (ppm)--corrected:			1.12

BIO-SAMPLE COLLECTING DEVICES: Van Veen

BIO-DATA REMARKS: Mullet, blue crab

CORE SAMPLE: CORE DEVICE: Van Veen core

TYPES OF SAMPLES TAKEN: Biology: X

Chemistry:

Hydrocarbons: ____

Trace Metals: X

Nutrients: X

Microbiology: X

Sediment: X

REMARKS: (Alligator?) coming out of river. Many Roseate Spoonbills, Black Skimmers, Caspian Tern, Louisiana Heron, Great Blue Heron, Little Blue Heron.

Surface H_2S: <0.1 ppm

C.E.M. STATION DATA SHEET

PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Parker

STATION: TB-16 DATE: 2 VIII 72 TIME: 09:00 DEPTH: 7 ft.

LOCATION: Lat. 29° 42' 45" N Long. 94° 50' 20" W

Off TriCity Point midway between Private Buoy and channel 1/2 mile offshore near dredge wreck

WIND SPEED: 7-8 mph WIND DIRECTION: SW

PARAMETERS:	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	28.3°C	27.0°C.	
Turbidity (JTU):		62	
Salinity (o/oo):			17.0
Clorinity: (o/oo)			15.6
pH:			7.4
Eh (MV):			129
O_2 (ppm): Light Bottle:	Dark Bottle:		12
Nitrate plus Nitrites (ppm)--corrected:			.06
Orthophosphate (ppm)--corrected:			1.0

BIO-SAMPLE COLLECTING DEVICES: Van Veen

BIO-DATA REMARKS: Mullet; shrimp trawler

CORE SAMPLE: CORE DEVICE:

TYPES OF SAMPLES TAKEN: Biology: X

Chemistry:

Hydrocarbons: ____

Trace Metals: X

Nutrients: X

Microbiology: X

Sediment: X

REMARKS:

Surface H_2S: <0.1 ppm

C.E.M. STATION DATA SHEET

PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Miller

STATION: TB-17 DATE: 2 VIII 72 TIME: 10:13 DEPTH: 7 1/2 ft.

LOCATION: Lat. 29° 40' 55" N Long. 94° 51' 10" W

Just south of Fisher's shores; 1/2 mile from shore north of Umbrella Point

WIND SPEED: 30 mph, Squall WIND DIRECTION: S

PARAMETERS:	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	25°C.	27°C.	
Turbidity (JTU):		53	
Salinity (o/oo):			17.5
Clorinity: (o/oo)			16.0
pH:			8.42
Eh (MV):			--
O_2 (ppm): Light Bottle:		Dark Bottle:	13
Nitrate plus Nitrites (ppm)--corrected:			.095
Orthophosphate (ppm)--corrected:			.99

BIO-SAMPLE COLLECTING DEVICES: Van Veen

BIO-DATA REMARKS:

CORE SAMPLE: CORE DEVICE: Van Veen

TYPES OF SAMPLES TAKEN: Biology: X

Chemistry:

Hydrocarbons:

Trace Metals: X

Nutrients: X

Microbiology: X

Sediment: X

REMARKS:

Surface H_2S: <0.1 ppm

C.E.M. STATION DATA SHEET
PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Miller, Parker
STATION: TB-18 DATE: 2 VIII 72 TIME: 11:00-11:18 DEPTH: 5 ft.
LOCATION: Lat. 29° 39' 30" N Long. 94° 52' 50" W

Just South of Umbrella Point -- 500 yards offshore

WIND SPEED: **7 mph** WIND DIRECTION: S

PARAMETERS:	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	24.0°C	27.0°C	
Turbidity (JTU):		67	
Salinity (o/oo):			17.0
Clorinity: (o/oo)			15.6
pH:			8.40
Eh (MV):			--
O_2 (ppm): Light Bottle:		Dark Bottle:	13
Nitrate plus Nitrites (ppm)--corrected:			.011
Orthophosphate (ppm)--corrected:			1.1

BIO-SAMPLE COLLECTING DEVICES: Van Veen; corer; plankton

BIO-DATA REMARKS:

CORE SAMPLE: CORE DEVICE: Corer

TYPES OF SAMPLES TAKEN: Biology: X
Chemistry:
Hydrocarbons: ____
Trace Metals: X
Nutrients: X
Microbiology: X
Sediment: X

REMARKS:

Surface H_2S: <0.1 ppm

C.E.M. STATION DATA SHEET

PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Miller, Parker

STATION: TB-19 DATE: 2 VIII 72 TIME: 11:35-11:43 DEPTH: 11 ft.

LOCATION: Lat. 29° 37' 05" N Long. 94° 51' 50" W

3 Miles off Umbrella Point to middle of lower end of bay

WIND SPEED: 7-9 mph WIND DIRECTION: S

PARAMETERS:	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	25.3°C.	28°C.	
Turbidity (JTU):		28	
Salinity (o/oo):			17.5
Clorinity: (o/oo)			16.0
pH:			8.41
Eh (MV):			--
O_2 (ppm): Light Bottle:		Dark Bottle:	11
Nitrate plus Nitrites (ppm)--corrected:			.06
Orthophosphate (ppm)--corrected:			1.0

BIO-SAMPLE COLLECTING DEVICES: Van Veen

BIO-DATA REMARKS:

CORE SAMPLE: CORE DEVICE: Van Veen

TYPES OF SAMPLES TAKEN: Biology: X

Chemistry:

Hydrocarbons: _____

Trace Metals: X

Nutrients: X

Microbiology: X

Sediment: X

REMARKS:

Surface H_2S: <0.1 ppm

C.E.M. STATION DATA SHEET

PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Miller, Parker

STATION: TB-20 DATE: 2 VIII 72 TIME: 11:51-12:05 DEPTH: 11 ft.

LOCATION: Lat. 29° 38' 40" N Long. 94° 50' 20" W

3 miles off Umbrella Point course 30° from 19 -- 5 minutes running.

WIND SPEED: 8 mph WIND DIRECTION: S

PARAMETERS:	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	27°C.	28.0°C.	
Turbidity (JTU):		34	
Salinity (o/oo):			18.3
Clorinity: (o/oo)			16.8
pH:			8.35
Eh (MV):			--
O_2 (ppm): Light Bottle:		Dark Bottle:	13 (#1)
Nitrate plus Nitrites (ppm)--corrected:			.04
Orthophosphate (ppm)--corrected:			.95

BIO-SAMPLE COLLECTING DEVICES: Van Veen

BIO-DATA REMARKS: All previous H_2S from surface water samples.

CORE SAMPLE: CORE DEVICE: Van Veen

TYPES OF SAMPLES TAKEN: Biology: X

Chemistry:

Hydrocarbons: _____

Trace Metals: X

Nutrients: X

Microbiology: X

Sediment: X

REMARKS:

Bottom H_2S: <0.1 ppm

C.E.M. STATION DATA SHEET
PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Miller, Parker
STATION: TB-21 DATE: 2 VIII 72 TIME: 12:10-12:20 DEPTH: 11 ft.
LOCATION: Lat. 29° 38' 00" N Long. 94° 48' 20" W

2 miles on course 98° from Station 20 to middle of bay
Shell.

WIND SPEED: 12 mph WIND DIRECTION: S

PARAMETERS:	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	26°C.	27°C.	
Turbidity (JTU):		14	
Salinity (o/oo):			18.3
Clorinity: (o/oo)			16.8
pH:			8.47
Eh (MV):			--
O_2 (ppm): Light Bottle:		Dark Bottle:	13
Nitrate plus Nitrites (ppm)--corrected:			.055
Orthophosphate (ppm)--corrected:			.95

BIO-SAMPLE COLLECTING DEVICES: Van Veen

BIO-DATA REMARKS: Toad fish caught on yellow jig.

CORE SAMPLE: None CORE DEVICE:

TYPES OF SAMPLES TAKEN: Biology: X
Chemistry:
Hydrocarbons: ____
Trace Metals: X
Nutrients: X
Microbiology: ____
Sediment: X

REMARKS: Oyster shell bottom
Bottom H_2S: <0.1 ppm

C.E.M. STATION DATA SHEET

PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Miller, Parker

STATION: TB-22 DATE: 2 VIII 72 TIME: 12:46-12:58 DEPTH: 9 ft.

LOCATION: Lat. 29° 40' 40" N Long. 94° 48' 50" W

3 1/2 miles due East of Crowley's - center of bay

WIND SPEED: 10-12 mph WIND DIRECTION: S

PARAMETERS:	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	26°C	27.5°C.	
Turbidity (JTU):		32	
Salinity (o/oo):			17.9
Clorinity: (o/oo)			16.4
pH:			8.50
Eh (MV):			--
O_2 (ppm): Light Bottle:		Dark Bottle:	13
Nitrate plus Nitrites (ppm)--corrected:			.05
Orthophosphate (ppm)--corrected:			.96

BIO-SAMPLE COLLECTING DEVICES: Van Veen

BIO-DATA REMARKS:

CORE SAMPLE: CORE DEVICE: Van Veen

TYPES OF SAMPLES TAKEN: Biology: X

Chemistry:

Hydrocarbons: ____

Trace Metals: X

Nutrients: X

Microbiology: X

Sediment: X

REMARKS:

Bottom H_2S: <0.1 ppm

C.E.M. STATION DATA SHEET

PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Miller, Parker

STATION: TB-23 DATE: 2 VIII 72 TIME: 13:05-13:12 DEPTH: 9 ft.

LOCATION: Lat. 29° 42' 00" N Long. 94° 48' 00" W

3 1/2 miles off TriCity Point--5 minutes running from TB-22

WIND SPEED: 12-13 mph WIND DIRECTION: S

PARAMETERS:	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	27.5°C.	27°C.	
Turbidity (JTU):		30	
Salinity (o/oo):			16.2
Clorinity: (o/oo)			14.8
pH:			8.4
Eh (MV):			--
O_2 (ppm): Light Bottle: DO- 15 Dark Bottle:			lost
Nitrate plus Nitrites (ppm)--corrected:			.075
Orthophosphate (ppm)--corrected:			.98

BIO-SAMPLE COLLECTING DEVICES: Van Veen

BIO-DATA REMARKS:

CORE SAMPLE: CORE DEVICE: Van Veen

TYPES OF SAMPLES TAKEN: Biology: X

Chemistry:

Hydrocarbons: ____

Trace Metals: X

Nutrients: X

Microbiology: X

Sediment: X

REMARKS:

Bottom H_2S: <0.1 ppm

C.E.M. STATION DATA SHEET

PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Miller, Parker

STATION: TB-24 DATE: 2 VIII 72 TIME: 13:38-13:45 DEPTH: 11 ft.

LOCATION: Lat. 29° 45' 25" N Long. 94° 41' 40" W

Trinity River at Anahuac up from landing at Marker 28

WIND SPEED: 6-8 mph WIND DIRECTION: S

PARAMETERS:	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	27.3°C.	28°C.	
Turbidity (JTU):		19	
Salinity (o/oo):			11.8
Clorinity: (o/oo)			10.8
pH:			8.1
Eh (MV):			--
O_2 (ppm): Light Bottle:		Dark Bottle:	9
Nitrate plus Nitrites (ppm)--corrected:			.06
Orthophosphate (ppm)--corrected:			0.68

BIO-SAMPLE COLLECTING DEVICES: Van Veen

BIO-DATA REMARKS: Red-wing blackbird; warblers; *Rangia* on bottom, some live.

CORE SAMPLE: None CORE DEVICE:

TYPES OF SAMPLES TAKEN: Biology: X

Chemistry:

Hydrocarbons: ____

Trace Metals: X

Nutrients: X

Microbiology: no core

Sediment: X

REMARKS:

Bottom H_2S: 0.1 ppm

AD-A095 862 COASTAL ECOSYSTEMS MANAGEMENT INC FORT WORTH TX F/G 8/8
ENVIRONMENTAL ASSESSMENT OF THE TRINITY RIVER DISCHARGE ON PROD--ETC(U)
SEP 72 R H PARKER, D E SOLOMON, G D SMITH DACW63-72-C-0142

UNCLASSIFIED NL

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C.E.M. STATION DATA SHEET
PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Parker
STATION: TB-25 DATE: 3 VIII 72 TIME: 09:20 DEPTH: 2 ft.
LOCATION: Lat. 29° 46' 05" N Long. 94° 41' 50" W

Nearly at end of Brown's Pass in Delta Marsh

WIND SPEED: 8-10 mph WIND DIRECTION: SE

PARAMETERS:	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	28°C.	27°C.	
Turbidity (JTU):		35	
Salinity (o/oo):			--
Clorinity:			--
pH:			8.5
Eh (MV):			--
O_2 (ppm): Light Bottle:		Dark Bottle:	--
Nitrate plus Nitrites (ppm)--corrected:			.06
Orthophosphate (ppm)--corrected:			.56

BIO-SAMPLE COLLECTING DEVICES: Hand

BIO-DATA REMARKS: Snowy Egrets, Gar, Grackles, Great Blue Heron, Louisiana Heron

CORE SAMPLE: 10 cm CORE DEVICE: Core tube push in

TYPES OF SAMPLES TAKEN: Biology: X
Chemistry:
Hydrocarbons: ____
Trace Metals: ____
Nutrients: X
Microbiology: X
Sediment: X

REMARKS: Picture of area and along cut. Large log.

C.E.M. STATION DATA SHEET

PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Parker

STATION: TB-26 DATE: 3 VIII 72 TIME: 10:00 DEPTH: 2 ft.

LOCATION: Lat. 29° 46' 50" N Long. 94° 43' 30" W

500 yards from end of Jack's Pass

Trinity Delta, left side of bank

WIND SPEED: 12 mph WIND DIRECTION: SE

PARAMETERS:	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	28°C.	27°C.	
Turbidity (JTU):		25	
Salinity (o/oo):			--
Clorinity:			--
pH:			8.4
Eh (MV):			--
O_2 (ppm): Light Bottle:		Dark Bottle:	11
Nitrate plus Nitrites (ppm)--corrected:			.05
Orthophosphate (ppm)--corrected:			.59

BIO-SAMPLE COLLECTING DEVICES: Light and Dark Bottle Productivity

BIO-DATA REMARKS: 2 alligators at river end of Brown's Pass (small); Jack's Pass--Roseate Spoonbill rookery

CORE SAMPLE: 10 cm CORE DEVICE: Push Core

TYPES OF SAMPLES TAKEN: Biology: X

Chemistry:

Hydrocarbons: ____

Trace Metals: X

Nutrients: X

Microbiology: X

Sediment: X

REMARKS: Morning glories; low plants in water; few canes on small levee

C.E.M. STATION DATA SHEET

PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Parker

STATION: TB-27 DATE: 3 VIII 72 TIME: 11:15 DEPTH: 1 ft.

LOCATION: Lat. 29° 53' 15" N Long. 94° 43' oo" W

1 mile into Mac Bayou, 10 miles above I-10 on Trinity Shiloh quadrangle

WIND SPEED: 0 mph on ground 10-12 mph above forest WIND DIRECTION: SE

PARAMETERS:

	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	31.0°C.	30°C.	
Turbidity (JTU):		37	
Salinity (o/oo):			--
Clorinity:			--
pH:			7.7
Eh (MV):			--
O_2 (ppm): Light Bottle:		Dark Bottle:	8
Nitrate plus Nitrites (ppm)--corrected:			.07
Orthophosphate (ppm)--corrected:			.2

BIO-SAMPLE COLLECTING DEVICES: Core

BIO-DATA REMARKS: Swamp, Cypress knees, willow

CORE SAMPLE: CORE DEVICE: Core

TYPES OF SAMPLES TAKEN: Biology: X

Chemistry:

Hydrocarbons: ____

Trace Metals: X

Nutrients: X

Microbiology: X

Sediment: X

REMARKS: Photos

C.E.M. STATION DATA SHEET
PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Parker
STATION: TB-28 DATE: 3 VIII 72 TIME: 12:00 DEPTH: 2 ft.
LOCATION: Lat. 29° 51' 25" N Long. 94° 43' 00" W

End of Lake Pass at entrance to Lake Charlotte

Anahuac Quadrangle Sheet

WIND SPEED: 6-10 mph WIND DIRECTION: SE

PARAMETERS:	AIR	WATER SURFACE	WATER BOTTOM
Temperature:	30.0°C.	--	
Turbidity (JTU):		28	
Salinity (o/oo):			--
Clorinity:			--
pH:			7.7
Eh (MV):			--
O_2 (ppm): Light Bottle:		Dark Bottle:	9
Nitrate plus Nitrites (ppm)--corrected:			.08
Orthophosphate (ppm)--corrected:			.25

BIO-SAMPLE COLLECTING DEVICES: Core

BIO-DATA REMARKS: Great Blue Heron; cypress and willow lined levee; marsh at end; big orb spiders spanning bayou (large number)

CORE SAMPLE: CORE DEVICE: push core

TYPES OF SAMPLES TAKEN: Biology: X

Chemistry:

Hydrocarbons: ____

Trace Metals: X

Nutrients: X

Microbiology: X

Sediment: X

REMARKS: Strong current into lake

C.E.M. STATION DATA SHEET

PROJECT: Trinity Bay PERSONNEL: Smith, Solomon, Parker

STATION: TB-29 DATE: 4 VIII 72 TIME: 11:00 DEPTH: shore

LOCATION: Lat. 29° 33' 25" N Long. 94° 36' 30" W

End of shell road on Anahuac Wildlife Refuge on edge of salt marsh and East Bay

WIND SPEED: WIND DIRECTION:

PARAMETERS:	AIR	WATER SURFACE	WATER BOTTOM
Temperature:			
Turbidity (JTU):			
Salinity (o/oo):			
Clorinity:			
pH:			
Eh (MV):			
O_2 (ppm): Light Bottle:	Dark Bottle:		
Nitrate plus Nitrites (ppm)--corrected:			
Orthophosphate (ppm)--corrected:			

BIO-SAMPLE COLLECTING DEVICES: Core

BIO-DATA REMARKS: Took core for bacteriology, No Water Sample

CORE SAMPLE: CORE DEVICE:

TYPES OF SAMPLES TAKEN: Biology: ____

Chemistry:

Hydrocarbons: ____

Trace Metals: ____

Nutrients: ____

Microbiology: X

Sediment: X

REMARKS:

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